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A Review of Chemical Demineralization and Desulphurization of High Ash & High Sulphur Lignite Coal

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ABSTRACT

Globally, large reserves of low grade or lignite coal are available. Low-ranking coal contains high mineral content, moisture content, and low calorific value. The major problem in coal is sulphur and ash When used for combustion, this type of coal imposes harmful impacts on the environment. It results in the production of greenhouse gases and ash, which are hazardous for the environment and human health. Usually, the demineralization and desulphurization process is used to remove the minerals matters before its use in industrial processes such as combustion, carbonization, gasification and liquefication. Which are harmful to the environment if combusted untreated. Therefore, the number of upgrading technology is being used to reduce the mineral matters from coal and save the environment. The current paper reviews the potential of demineralization and desulphurization processes to enhance the usability of lignite coal. Moreover, it focuses on preserving the high-grade coal which is already depleted in abundance.

Keywords: lignite coal; Mineral matters; Demineralization; Desulphurization

INTRODUCTION

Lignite Coal is a fossil fuel. It is cheapest source of energy generation. Direct use of coal has several drawbacks including the formation of ash, moisture content, low level of heating value, and environmental contamination (Sittisun et al. 2015). Coal combustion causes several environmental problems. Minerals in coal are mostly eliminated by conventional combustion methods as ash from boilers and particulate control devices, or as particles released into the atmosphere by combustion (Zhang et al. 2017). Lignite coal is the world's cheapest fossil fuel. Globally, lignite coal is available in large quantities (Zhu et al. 2021). After petroleum and other fuels, second-largest source of energy in the world is coal. It is used to generate electricity as day by day energy crises are increasing. According to world coal association, 70% of the coal is used for steel production and 41% coal is used to generate electricity. Utilization of coal in different purpose increase the environmental problems due to emissions of solids and gaseous pollutants. It is combustible and incorporated with different mineral matters which have bad effects on the environment (M, C. 2009). The mineral contents present in coal are different which may be calcite, pyrite, gypsum, quartz, oxygen, and H, N, S. Pakistani coal is considered highly polluting due to its high sulfur and ash content. So the presence of these minerals badly affects the specific characteristics of coal and reduces the calorific value (Chen et al. 2013; Duz et al. 2009;).There are two types of processes to get rid of such impurities: Physical and Chemical Cleaning Processes. The chemical cleaning process is highly essential to demineralize the coal before using it in the industries and for power generation. Therefore, before using low-grade coal, it should be demineralized and desulphurized before utilization in steel, thermal plants and cement industries, etc. To improve the combustion qualities of coal, it is important to be demineralized and desulphurized (Alam, R., 2012; Rubiera et al. n.d.)

COAL FORMATION

Coal is primarily used as solid fuel. Coal formed after the conversion of dead plant decays into peat and ultimately converted into coal in the absence of oxygen. Coal goes through several changes by pressure and heat. The biochemical changes of coal are produced by the bacteria release of hydrogen, oxygen, and carbon (Friedman & Warzinski, 1977 n.d.).Coal formation begins as forested swamps die and they sink under the water. Sediments like clay, sand, and salt may also deposit when coal forms (Groppo, 2017). During the coal formation, as pressure increases with time, the impurities and moisture are squeezed out. Peat, lignite, bituminous and anthracite coal are the four stages of coal formation (Friedman & Warzinski, 1977b). These stages depend upon the conditions such as high temperature and high pressure in which the plants are buried and form coal. Higher ranking coal is achieved when it contains less moisture, less gases and higher heating value than lower-ranking coal (Arnold 2013; Pratima.Pandey et al. 2015). Table no 2. shows the formation of coal with their properties like moisture content, volatile matters, oxygen, carbon percentage and calorific value. The first stage of the formation of coal is peat, it is soft, contains a lot of fibrous, water and spongy texture. The color of the lignite coal is dark brown and contains traces of plants. It is used only when there is no alternative source of fuel available. Bituminous coal is a lump of middle-rank coal between sub-bituminous and anthracite coal used as the industrial source, it has a higher heating value (Btu) and it's mostly used for electricity generation (C. A. Wang et al. 2011). Bituminous coal is black and dull containing fewer carbons. Anthracite coal is formed in the last stage of formation. It is hard and black coal formed during high temperature and high pressure (Rahman et al. n.d.). Anthracite coal has the texture of the rock and some luster. It produces a small flame, little smoke and has less percentage of ash (Reza, 2007).

MINERAL CONTENT IN COAL

Coal is usually rich in different types of mineral impurities such as calcite, gypsum, quartz, pyrite, oxygen, hydrogen, Nitrogen and Sulphur. Ash is always increased with oxides of K_2O, Fe_2O, Al_2O_3, and SiO_2. The impermissible limits of ash content in the coal reduces its quality and calorific value. The presence of mineral impurities (calcite, pyrite, gypsum, quartz, etc) badly affects the huge overall quality of coal. Two types of processes are used to get rid of such impurities; Chemical and Physical Cleaning processes. The Chemical Cleaning Process in comparison to Physical is more expensive. It is highly essential to demineralize the coal before using it in the industries and for power generation (Huggins 2002; Smoot 1993; Yu, D., Xu, M., Zhang, L., Yao, H., Wang, Q., Ninomiya 2007). Mineral matters are founded in coal during its formation. Mineral contents are divided into inherent and extraneous. The inherent minerals are quartz, clays, carbonate, and pyrite, extraneous as shale, sand, stones, and rocks (Bryers 1996; Grigore et al. 2008; Vassilev & Vassileva 2009). Coal is used for combustion to get energy, but without demineralization, ash is formed after complete combustion. Ash is intermixed into low-rank coal, the presence of high ash creates industrial problems such as technical difficulties and also ash disposal requirement (Diehl et al. 2012; Kolker 2012; Ward 2002). The mineral matter bound in coal harmfully affects the environment during utilization and processing industries. Therefore, before coal utilization, it is significant to eliminate the mineral matter. Sulphur in coal is also harmful and it is released during the combustion of coal. There are two types of Sulfur, one is inorganic and the other one is organic, both are harmful and release SO_2 during combustion. Using acid and alkali leaching treatments, we can demineralize and desulfurize coal before using combustion, liquification and gasification processes (S. K. Behera et al. 2018b).

TABLE 1. Coal Formation Stage and their Properties (Pratima Meshram B.K. Purohit M.K. Sinha S.K. Sahu B.D. Pandey, 2015)

Coal types	Carbon content[b] (%)	Moisture[a] contents (%)	Volatile Matter[b] (%)	Oxygen content[b] (%)	Calorific value[a] (kcal/kg)
Peat	>60	~ 75	69-63	< 23	3500
Lignite	65-70	35-55	63-53	23	4000-4200
Sub-bituminous –C	70-72	30-38	53-50	20	4200-4600
Sub-bituminous-B	72-74	25-30	50-46	18	4600-5000s
Sub-bituminous-A	74-76	18-25	46-42	16	5000-5500
High volatile bituminous-C	76-78	12-18	46-42	12	5500-5900
High volatile bituminous-B	78-80	10-12	42-38	10	5900-6300
High volatile bituminous-A	80-82	8-10	38-31	8	6300-7000
Medium V bituminous	82-86	8-10	31-22	4	7000-8000
Low V bituminous	86-90	8-10	22-14	3	8000-8600
Semi Anthracite	90	8-10	14-8	3.5	7800-8000
Anthracite	<92	7-9	8-3	4.5	7600-7800

[a] shows as received basis
[b] shows as dry ash free basis

GLOBAL COAL SCENARIO

Coal is utilized as a source of energy generation in the world. More than 90% of the coal reserves in the world are in just ten countries which are shown in Table no 3. The United States is at the top of the list in the world while Russia and Australia are second and third. According to December 2018 total coal stood approximately 250.3 billion tons counting for almost (24%) of coal reserves work verified. The United States is also the world's second biggest coal consumer & producer (685.1 million tons) of coal, and compared to 9.3% of the world's total at the end of 2018. The whole country accounts for a total 8.4% of coal consumption in the world and around 27% of coal is utilized for the generation of electricity. Russian federation confirmed 15.2% of the world's total coal reserves. Russia produced 421Mt of coal and consumed 89Mt oil equivalent of coal in the year 2018. Table 1.3 shows the world survey of coal in December 2018 and explains that the Australia's confirmed coal reserves of 147.48Bt estimated approximately 14% of the total verified coal reserves in the world (BP Statistical Review of World Energy 2019).

According to coal reserves data, Pakistan is the 7th largest country with coal deposits in the world. The coal deposits range up to 185 million tons of which 97% occurs as lignite coal whereas 3% as bituminous and sub-bituminous coal. Coal remains the backbone of the steel, iron and cement industries. In Pakistan, coal is available in the largest quantity. It is solid fuel and the largest source of energy for the generation of electricity (Sadiq Malkani, 2012).

TABLE 2. Mineral Content in Coal (Mukherjee 2003)

Mineral matters	Group	Formula
Clay	Kaolinite	$Al_2SiO_5(OH)_4$
	Muscovite	$KAl_2(Si_3Al)\ O_{10}\ (OH)_2$
	Illite	$K_{1-1.5}\ Al_4\ [Si_{6-7}Al_{1-1.5}O_{20}]\ (OH)_4$
	Smectite	$(Na, C\ a.nH_2O)\ (Al_{2y}\ Mg_y)(OH)_2\ (Si_{2x}\ Al_x)O_{10}$
Oxides	Quartz	SiO_2
	Rutile	TiO_2
	Anatase	
Carbonates	Calcite	$CaCO_3$
	Aragonite	$CaMg(CO_3)_2$
	Dolomite	$Ca(FeMg)CO_3$
	Ankerite	$FeCO_3$
	Siderite	$MnCO_3$
	Rhodochrosite	
Scapolite	Analcime	$Na\ AlSi_2O_6\ H_{2O}$
Sulfates	Gypsum	$CaSO_4\ .2H_2O$
	Alunite	$KAl_3(SO_4)_2(OH)_6$
	Jarosite	$KFe_3\ (SO_4)_2\ (OH)_6$
Sulfides	Pyrite	FeS_2
	Marcasite	
Phosphates	Apatite	$Ca_5(PO_4)_3(F, Cl, OH)$
	Crandallite	$CaAl_3(PO_4)_2(OH)_5\ H_2O$
	Gorceixite	$BaAl_3(PO_4)_2(OH)_5\ H_2O$
	Goyazite	$SrAl_3(PO_4)_2(OH)_5\ H_2O$
Feldspars	Orthoclase	$KAlSi_3O_8$
	Microcline	
	Plagioclase	$Na[AlSi_3O_8]–Ca[Al_2Si_2O_8]$

TABLE 3. Coal reserves of some countries at the end of 2018 (BP Statistical Review 2019)

Countries	Anthracite & Bituminous coal	Sub-bituminous & lignite	Total
United State	220167	30052	250219
Indonesia	26122	10878	37000
India	96468	4895	101363
China	130851	7968	138819
Australia	70927	76508	147435
Germany	3	36100	36103
Ukraine	32039	2336	34375
Poland	20542	5937	26479
Kazakhstan	25605	-------------	25605
South Africa	9893	-------------	9893
New Zealand	826	6750	7574
Serbia	401	7113	7513
Brazil	1548	5048	6595
Canada	4345	2237	6583
Pakistan	207	2857	3064
Czech Republic	110	2547	2657
Mexico	1161	52	1212
Spain	867	318	1188
Thailand	----------------	1063	1062

DEMINERALIZATION AND DESULPHURIZATION OF COAL

The major minerals in a coal are sulfide, pyrite, clay, quartz, calcite and carbonates. These are made up of the elements such as aluminum, oxygen, iron, calcium, silicon, iron and sulfur (H. Karaca, Fuel, et al. n.d.; Varol et al. n.d.).These mineral matters are bound in coal by single crystals or clusters of crystals and depend on the original composition of coal. These minerals convert into ash or gases form during the combustion. Demineralization and desulphurization is a process that removes the mineral matters from the coal using the alkali and acid (Mukherjee & Borthakur n.d.; Steel, Fuel, & 2001, n.d.).There are two types of minerals associated with coal one is chemically bounded and the other is physically bound. Physical and chemical methods are used for the demineralization and desulphurization of coal, physical method is used for removing the mineral from the surface. Chemical method is more efficient than the physical method, chemical method reached out more minerals than the physical method. In many industries, it is important to use such coal that should be pure otherwise it will create operational problems (Araya et al. n.d.; Meshram et al. 2015). It is relative to the high percentage of moisture, Sulphur and ash percent that will create operational and environmental problems (Baláž et al. n.d.). Impurities directly affect the specific characteristics of coal, i.e. it reduces the heating value of coal, increase the ash percentage, create the environmental problems and increase the cost of industries by choking the pipes and boilers (Ayhan et al. 2005; B. P. Baruah et al. 2006; B. P. Baruah & Khare, 2007; M. Baruah et al. n.d.; Blanchard et al. n.d.; Bolat et al. n.d.; Çulfaz et al. n.d.; Dash et al. 2013a; Lee et al. n.d.; Markuszewski et al. 1978). To enhance the quality of coal, the impurities must be removed. After removing the impurities of coal heating values increases and the percentage of ash decreases. Demineralization (remove minerals) and desulphurization (remove Sulphur) of coal by chemical methods involve using the acid and bases like $Ca(OH)_2$, NaOH, KOH and the acidic solutions like HNO_3, HCL, HF, H_2O_2 and H_2SO_4 (Varol et al. n.d.).

PHYSICAL BENEFICIATION METHOD

The physical beneficiation process of coal removes the mineral matters from coal through washing, oil agglomeration and froth flotation (Bryers, 1996; Grigore et al. 2008). The physical beneficiation process removes the ash forming material, upgrades the coal and improves its quality by reduction of ash and Sulphur. A Physical process is a simple operation to remove minerals from the surface of coal and is inefficient for ash and Sulphur. The physical process has limited application. The physical treatment process is based on surface properties and differences in the specific gravity of coal. By physical process, those minerals having magnetic properties that remove in the magnetic separator and those based on electric properties remove by electrostatic or conductivity separator(Pratima et al, 2015). The physical process of coal is also based on particle sizes such as Oil agglomeration and the Froth flotation technique has been used for finer particle size (Smoot, 1993).

CHEMICAL BENEFICIATION OF COAL

Chemical beneficiation process removes the mineral matters which are bounded in low-grade coal. Low grade coal contains more minerals than the high-rank coal, has a higher percentage of ash and associated with lower heating value. In comparison to physical techniques, the chemical method removes higher impurities. Chemical cleaning process using acid and alkali are more beneficent in reducing the ash formation of minerals. Chemical demineralization and desulphurization process accomplished by alkali alone and acid or alkali followed acid. Various researchers have investigated the leaching of coal to remove minerals using alkali i.e. NaOH (S. Karaca et al. n.d.), NaOH followed by acids (Grigore et al. 2008), KOH and acids (Vassilev & Vassileva, 2009), used for removing minerals Na_2CO_3 (Ward, 2002), $Ca(OH)_2$ followed by washing with acid (Kolker, 2012), mineral acids viz. HNO_3 (Alam et al. n.d.; Ishaq et al. n.d.; Rodríguez et al. n.d.), HCl (Mukherjee et al. n.d.), H_2SO_4 (Paul et al. n.d.; Vasilakos et al. n.d.), oxidizing agents, H_2O_2(H. Karaca, Technology, et al. n.d.), $Fe_2(SO_4)_3$(*Meyers RA. Hydrocarbon Process 1975 - Google Scholar*, n.d.), $K_2Cr_2O_7$(Ali et al. n.d.), NaOCl (W. Li & Cho, 2005), HF then HNO_3 (Steel, Fuel, & 2003, n.d.) and another sequential leaching of coal by NaOH and followed by H_2SO4 (Nabeel et al. 2009).

ALKALI LEACHING

To remove mineral contents from coal using alkali leaching process is significant in removing the kaolinite, quartz and other mineral matters. The kaolinite and quartz are converted into hydrated alkali bearing like silicate, alumina-silicate complex like sodalities. Turkish lignite coal was treated with NaOH for demineralization and 91% of minerals were removed (Saydut et al. 2011). By treatment of NaOH at 300˚C to remove the pyrite Sulphur and 40% organic Sulphur were removed from coal (Diehl et al. 2012). Similarly, low rank coal was treated with KOH for 2 hr at the room temperature with 50% Sulphur removed after 2 hr treatment process (Ken & Nandi, 2018a). Treatment of alkali for deashing and desulphurization of two types of coal with the level of 2-19% and 16-30% was obtained at temperature 95˚C. The results show that the chemical treatment of coal by MCL process removes 95% of the ash forming impurities and 90% of Sulphur can be removed from the coal (Chriswell et al. 1991). Lee et al. successfully removed 29% of total sulphur and 30% ash via NaOH treatment for 8 hours at 80˚C (Lee et al. n.d.).Wang et al. treated two different coals (high and low ash coals) 15.5% -7% applied caustic wash to remove major components kaolinite and quartz, removal of Ca and Fe compound depends on mineral contents which are associated with coal. Short time and 370˚C temperature of heating for mineral removal is required to react the minerals matters (Kaushik et al. n.d.; Z. Wang et al. n.d.). In another study, subbituminous coal was treated with NaOH for removing the ash and sulphur from coal. The ash and Sulphur were removed more with increasing the temperature, time, with decreasing the particle size of coal and increasing the concentration of NaOH in rang study, the solubilized products were about 28 by wt % achieved by 8h at a temperature of 80˚C using a concentration of 10 g/ dm^3 and particle size rang 125-177µm, ash decrees by 29% by wt. and Sulphur decreases 30% by weight (Lee et al. n.d.). Several other researchers observed that using aqueous solution leads to the removal of ash and inorganic Sulphur present in the coal (Babich et al. n.d.)

LEACHING OF COAL WITH ALKALI FOLLOWING

Alkali leaching and acid washing both are very effective in reducing the ash content in coal as formed sodalities and soda-aluminosilicate during chemical treatment of coal with NaOH which are mostly soluble by using the acid treatment. Mild acid washing also reduces extra sodium compounds and acid-soluble minerals along with quartz, pyrites kaolinites and some organic Sulphur (Mukherjee et al. n.d.). According to Duz et al. treated the coal with a solution of NaOH and followed by acid at the temperature of 400˚C for 45 minutes, 100% inorganic & 70% of organic sulfur and ash contents were minimized. This result was achieved by the combined treatments process (Duz et al. 2009). Yang et al, introduced the three-step treatment process of coal NaOH solution treated by both sulphuric acid and then nitric acid treatment. It shows that alkali (NaOH) treatment form sodalities and sodaluminosilicates, sulphuric acid reacts with metals and dissolves most silicate, aluminates and action of nitric acid could reduce more Sulphur and iron by dissolving pyrites (Hu et al. 2018).

According to Wang et al. he introduced an Australian Newstan coal and shows that 5% CaO followed by HCL at temperature 340˚C and time duration 120 min and this reached about 76% of ash removal (M. Wang et al. 2020). Mukherjee and Borthakur carried out demineralization and desulphurization of two Assam coal-carrying 10.4% and 8.4% ash in coals and sulphur percentage 4.3%. demineralization and desulphurization achieved by the action of 16% of an aqueous solution of NaOH followed by 10% HCL at temperature of 90-95˚C and about 43%-50% ash reduced and 10% organic sulphur removed and inorganic sulphur completely removed (Mukherjee & Borthakur, n.d.). Kumar and Gupta showed that the Assam coking coal with the concentration of 500g/L NaOH at the temperature of 120˚C and 70% of demineralization was achieved (Kumar & Gupta, 1997). Sharma and Gihar treated the Indian coal by using alkali –acid leaching process for the reduction of sulphur and ash developed under milder ambient pressure condition and reported that coal samples were treated with alkali and(10 % aq. HCl 10% aq.H_2SO_4)in the second stage under reflux conditions and reported about 75% degree of demineralization of Indian coal (Sharma et al. n.d.).According to Nabeel low-grade coal after the combustion leading environmental pollution so it is important to use coal in power generation after the treatment of coal. Nabeel used 20% aq. NaOH solution followed by 10% H_2SO_4 under the reflux conditions. Treatment of coal with 1% or 5% aqueous NaOH and followed by acid with 1% or 5% H_2SO_4 for 2 hr, coal with only 5% aqueous NaOH solution is 20.3% and 70% degree of demineralization obtained by 5% H_2SO_4 acid. (Nabeel et al. 2009). According to Behera et al. to upgrade the low grade coal using the alkali-acid leaching of coal with different alkali concentration 50-150g/L and achieved the maximum degree of demineralization about 27.5% at 100g/L leaching shown in Figure 2, after alkali treatment followed by 20% H_2SO_4 acid and degree of demineralization increase up to 48%(S. K. Behera et al. 2018b). According to Mukherjee demineralization and desulphurization of coal increase by increasing the alkali concentration and formation of sodium aluminum silicate which can be decomposed by acid and it is possible to remove 43-50% ash from coal (Mukherjee & Borthakur, n.d.).Cleaning of coal is very important to remove the various minerals, 90% demineralization and desulphurization can be achieved by using chemical treatment (Dhawan & Sharma, 2019). According to Choudhury, To Demineralization of coal using NaOH and HCL by fractional factorial design under the optimum condition, particle size 0.22 mm temperature 90˚C and time 2hr at these conditions maximum deashing were observed (Choudhury, n.d.).Dash et al. showed that mineral matters can be removed by chemical demineralization achieved as alkali –acid leaching process (Dash et al. 2013a).M. Zahir Duz et al, Carried out the turkey coal to remove the impurities using the molten caustic leaching process followed by mild acid and reducing the significant amount of ash derived from minerals, pyrite sulphur and organic sulphur from low grade coal. The effect of the ratio of alkali-acid time and temperature on the demineralization of coal. The temperature used up to 200-400˚C and result achieved as ash reduced 18.31%-6.77% and sulphur reduced 7.54-1.01% and volatile matters from 47.80-12.41% reduced (Duz et al. 2009).

EFFECT OF ALKALI CONCENTRATION ON DEMINERALIZATION OF COAL

The alkali leaching method reduces most of the mineral constituents which are present in coal. Alkali reagents can penetrate the interior part of the coal matrix. The main purpose of alkalis is that it reacts with minerals in coal, alumina, silica, and clay-bearing minerals and is converted into hydrate alkali bearing silicate, aluminate and aluminosilicate complex sodalite (S. Behera et al. n.d.). Percent of demineralization increase with an increase in the alkali concentration. For reduction of ash coal sample treated with NaOH concentration of 10-40%, according to this article percentage of reduction of ash from coal increase with increasing of NaOH, the maximum reduction achieved at 30% of NaOH. Further, increase concentration ash reduction decrease because alkali reacts with silica and alumina. The formation of silicate and aluminate ions increases due to increasing the alkali concentration and form soluble sodium aluminosilicates and this can be decomposed by acid treatment (Kumar & Gupta, 1997). According to Sushanta K shows the same result, increase concentration of alkali from 50-150g/L degree of demineralization increase up to100g/L further increasing alkali concentration percent of demineralization decreases and the best result achieved at 100g/L as shown in Figure 2 (S. K. Behera et al. 2017).

During the leaching process, the possible reaction of adsorption complex silica is shown below.

$$SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O$$

$$Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$$

$$Na_2SiO_3(aq) + 2NaAl(OH)_4(aq) + NaOH(aq) + H_2O \rightarrow$$

$$[Na_a (AlO_2)_b (SiO_2)_c .NaOH.\ H_2O]$$

[Sodium aluminosilicate gel]

Gel converted into zeolite, sodalite, or nosalite it depends on alkali concentration (S. Behera et al. n.d.; S. K. Behera et al. 2018b; Singh et al. 2020; Yang et al. n.d.). Lolja explained that a chemical process like NaOH is more efficient in removing the pyrite sulphur. Total content which is associated with coal can be removed by alkali treatment (technology & 1999, n.d.). Friedman et al. reported that sodium hydroxide solution at a temperature of 300˚C completely removes the pyrite sulphur and 40% organic sulphur. Many other authors also explain that if increase the alkali and acid concentration or alkali to acid follow treatment during treatment percent of all types of sulphur removed (Friedman & Warzinski, 1977a).

EFFECT OF TIME DURATION

According to Faisal R, stirring time and temperature effects on the percent of ash removal and sulphur, to increase in time and temperature percent of demineralization and desulphurization also increase, further shows that the rate of sulphur removal is greater 40-60˚C than the 60-80˚C. The effect of time duration on both desulfurization, deashing of coal sample was considered in a range of 10 to 60 min and the results show that ash and sulphur removal increase from coal with increasing reaction time (Rehman et al. 2015)
According to Nabeel if increasing the time 1-24hr the degree of demineralization increase from the range 14.77- 44.18 % using alkali and followed by acid it further increase from 37.79-76.00 %. (Nabeel et al. 2009).

According to Bhupendra K suggested that concentration of alkali and time affects the degree of desulphurization. as increase time up to (6,12,18 and 24) percentage for removing sulphur increase up to (3.50,3.45,3.30 and 3.11(Ken & Nandi, 2018b).

According to Kumar (1997) to reduce the ash level leaching temperature increasing (50-120˚C) and time (30-180m). It reported that the best result was obtained at 120m and further increase time ash percent removed slowly as compared to 120m (Kumar & Gupta, 1997).

Alkali concentration and time duration both affect the ash removal from coal as explained in Figure 3, coal is treated for 2.5 h and 5 h and finally, the maximum ash is reduced at 2.5 h (Dash et al. 2013a)

EFFECT OF TEMPERATURE ON DEMINERALIZATION

Sushanta K treated coal at temperature 65-150˚C and stirring time was 60-120m and reported that maximum demineralization was obtained 23% and 45% at a temperature of 150˚C and less demineralization achieved at low temperature for alkali acid follow treatment (S. K. Behera et al. 2018a).

According to Faisal R temperature effects on the percent of ash removal and sulphur, shows that the rate of sulphur and ash removal is greater 40-60˚C than 60-80˚C (Rehman et al. 2015)

The effect of temperature on coal demineralization is explained in figure 5. Coal is successfully treated with 40% of NaOH and then followed by 10% HCL with temperature stared from 45˚C to 85˚C and degree of demineralization slowly increases (Dash et al. 2013b).

Faraz Anwar suggested that at a concentration of 50 % KOH time maximum of 150 min and temperature rang (25˚C and 75˚C) maximum desulphurization 74.2 achieved at 75˚C (Anwar et al. 2020).

Karaca et al. Reported that the Percent of sulphur removal increase with the increase in temperature from (30-60˚C) further increase in temperature from (60-90˚C) and sulphur percent reduce but slowly as shown in Figure 4. so best result obtained at a temperature of (30-60˚C) (H. Karaca, Fuel, et al. n.d.).

The experiment was conducted to check the effect of temperature on ash content in coal samples it is observed that a decrease in ash content was observed at higher temperatures due to an increase in reaction kinetics with temperature (Abdollahy et al. n.d.; C. Li et al. n.d.; Rahman et al. 2017; Wahab et al. 2015).

To determine the effect of temperature on coal demineralization, -30 mesh size of coal particle was selected and treated with alkali and 10% HCL. Temperature increases from 45˚C to 85˚C, the degree of demineralization gradually increases with an increase in temperature as shown in Figure 5.

EFFECT OF PARTICLE SIZE

Effect of particle size on the degree of demineralization of coal sample, treated two particle size as -30 mesh (0.50) and -72mesh (0.21) at time of 2.5h with alkali, followed by acid it observed that degree of demineralization increase with fine size of coal sample, in this case, study the different size of particles were taken, the -30 mesh size of coal gives the minimum percent of ash as 6.3% and for particle size -72 mesh sample, minimum ash content obtained 5.6% at same alkali concentration and acid treatment because finer size provides more surface area of coal is exposed and more mineral matters react with a solution of alkali and acid treatment (Dash et al. 2013b).

Sushanta K et al. investigated the effect of finer particle size of coal. In this investigation, coal was treated with a 50-150g/L solution and followed by a 20% H_2SO_4 acid treatment for 60-120m at the temperature of 65-150˚C. Further, he explained that the decrease in particle size -60 and -72 mesh particle size with increase the extent of demineralization,-72 mesh particle size has been found the most effective demineralization by combined treatment process(S. K. Behera et al. 2018a). Faisal Rehman experiment conducted for chemical treatment of coal using the only alkali and determine the effect of particle size of coal at (5% w/v) time 20, 40 and 60 and temperature of 40˚C, 60˚C, and 80˚C. He explained that the fine particle size of coal treated with 5% w/v alkali produces more surface area to react with alkali so more impurities dissolved and the percent of sulphur removal increase from coal. Further, he explained about effect of particle size on ash removal and reported that decrees in coal particle size lead to minimum removal of ash forming components due to the present of more minerals matters which react with alkali and form sodium aluminum silicates precipitates (Rehman et al. 2015). Faraz Anwar et al. suggested about three different variables like time, temperature and particle size and showed that a decrease in particle size positively improves the sulphur removal from coal (Anwar et al. 2020). Jatendar pal effect of particle size on chemical treatment process during the treatment coal sample was taken with different sizes of particles such as (53-75,75–106, 106–150) and 150–250 mm. the coal sample treated by combined method alkali –acid treatment NaOH 40% and HCL 10% for the time of 2 hr. results data observed that increase rang of particle size decrease the percent of ash content in coal sample 53-75mm and highest ash content obtained of particle size of 150-250mm (Singh et al. 2020). A. Wahab et al. study about the effect of coal molten caustic on coal demineralization and desulphurization at constant temperature 250˚C for one hr and different particle sizes from 60, 80 and 100 mesh size treated with caustic ratio 1:1, 1:2 and 1:3 washed 10% HCL solution. Results showed that increase in particle size from (60-100mesh) the percent of demineralization and desulphurization increase because small particle sizes have more surface area of contact with reactants (Wahab et al. 2015).

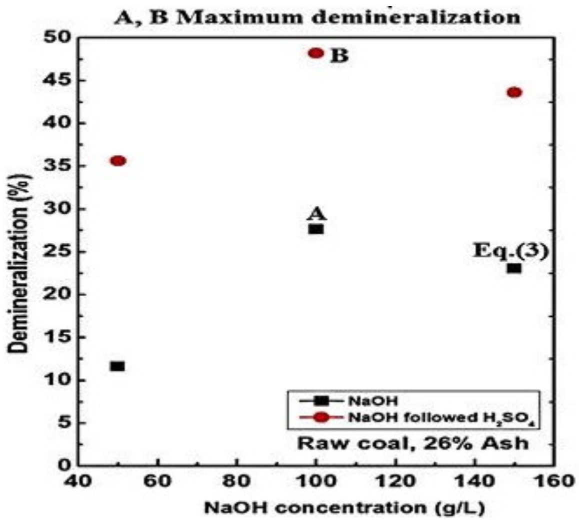

FIGURE 1. Effect of alkali and acid (S. K. Behera et al. 2017)

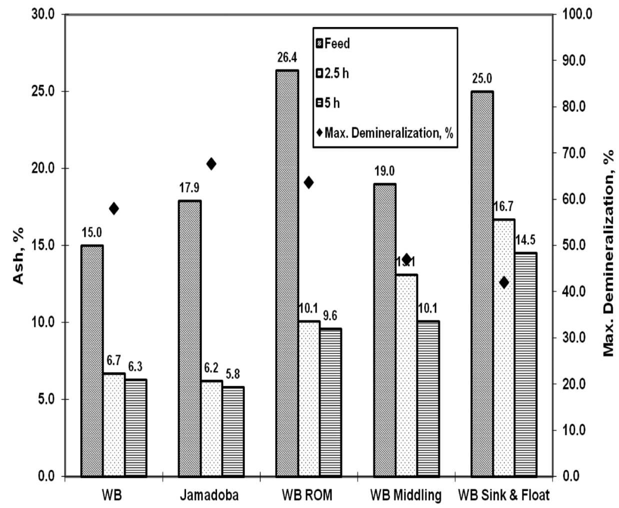

FIGURE 2. Effect of time on coal demineralization (Dash et al. 2013a)

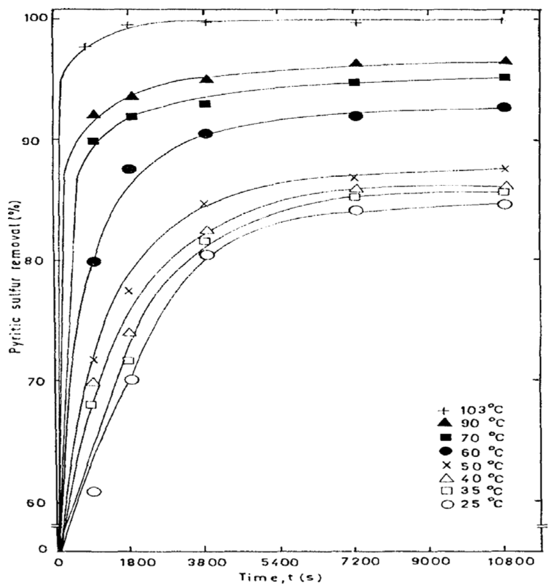

FIGURE 3. Effect of time on coal desulphurization (S. Karaca et al. n.d.)

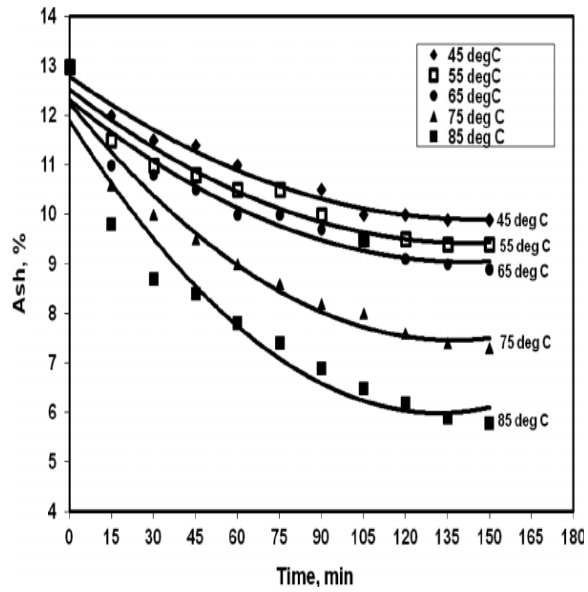

FIGURE 4. Effect of time on coal demineralization (Dash et al. 2013a)

APPLICATIONS

Coal plays important role in industries and it has two principal markets one is thermal coal and the other is metallurgical coal. The largest coal utilizer is the power generation industry as compare as other fuel industries. coal is a combustible material with combustible properties like volatile matter, heating value and activation energy. These properties depend upon the mineral and ash composition of the coal. Therefore, to use the coal in the industries, it needs to be cleaned to get rid of minerals thorough cleaning methods. Some disadvantages of direct utilization of coal for other fossil fuels are the emission of toxic gases, trace metal and greenhouse gasses. Mineral matter which is associated with coal is the problem of industries and the environment, the mineral matters harmfully affect during utilization of coal for power generation, cement production, metallurgical purpose and industrial fuel and for chemical making, to minimize these problems coal is treated with alkali and acid, demineralization and desulphurization process are used for the production of ultra-clean coal. This process is used for low grade coal by using the alkali and acid because Low grade coal is relative to high mineral matter. This process has been used for enhanced the quality of low grade coal.

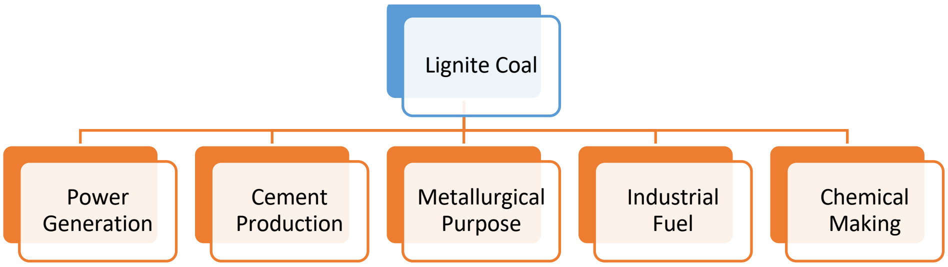

FIGURE 5. Applications of Lignite Coal

CONCLUSION

Coal has shown huge potential as an energy resource in the world. It carries significant applications especially for power generation, cement production, metallurgical purpose, industrial fuel and chemical making. Due to these significant application coal combustions create a serious problem of the environment when it contains a high concentration of minerals and sulphur contents, the present review paper study for demineralization and desulphurization of lignite coal. The associated benefits of using coal included, but not environmentally friendly, to make environmentally friendly treated it with two methods like physically and chemically, physically method removes minerals on the surface structure or organic minerals, which are bounded to the coal, chemically method is an effective method but it is expensive than the physical method due to requirement of chemicals. The combined physical and chemical method is more efficient for demineralization and desulphurization of coal and ultra clean coal can achieve by the combined method.

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DECLARATION OF COMPETING INTEREST

None

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