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INVESTIGATION OF LEACHING BEHAVIOUR OF SELECTED COAL

Bachelor Thesis

by

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Statutory Declaration

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Table of Contents

Content of Table

Content of Figure

Abstract

This bachelor thesis aimed to study chemical demineralization and desulphurization of selected coal by using various inorganic and organic acids, alkalis, oxidizing agents and their combination to reduce the ash and sulfur content of coal. Throughout the study, chemical enrichment of low-grade coal was an effective method of reducing minerals of low value coal to upgrade into high quality coal.

Currently global development is moving towards a clean energy but coal still plays an important role in producing energy supply worldwide. High quality coal reserves are gradually depleting while cost of the higher quality coal mining is becoming more and more expensive which leads to economic disadvantage. Fortunately, low grade coal reserves are still abundant and could be used as an alternative energy source to minimize the cost. Yet low grade coals are not only having high content of minerals and moisture which gives serious impact on their consumption but also along its usage the formation of unwanted, toxic metals and harmful gases emissions leads into critical environmental issues. Therefore, the purification of low grade coal using bacteriological, physical or chemical processes becomes extremely important. Physical enrichment methods have very limited effect on the low grade coals to produce low ash coals. In such low grade coals chemical enrichment method could reach much higher degree of demineralization due to its effect on the structure of coal. Chemical reagents diffuse inside the carbon matrix through the pores and subsequently dissolve the unwanted minerals.

Similarly, in Mongolia there are abundant coal reserves in several regions but high grade coals are depleting while low grade coals have high ash, moisture and sulfur content. Especially, the coals that have acceptable coking property but have high content of sulfur and ash are very suitable to be processed by chemical beneficiation method than bacteriological and physical methods.

Keywords: Coal chemical beneficiation, desulphurization, demineralization

Introduction

It is noted that humans started using a coal as an energy source as early as the cave man [1]. Coal as source of energy dominated the world for two hundred thousand to three hundred thousand years. Although nowadays world's development goes into the direction of clean energy, the era of coal is still continuing because until we found renewable energy that could replace coal completely as an energy source. On the other side the depleting hard coal reserves is another big issue we are facing today.

Mongolia has a huge coal reserve and exports high quality coking coal to China specifically mainly for Chinese steel producers which has great impact on the Mongolian economy. But Mongolian most of the coal exporting companies mine and export the layer with high quality coking coals of the deposit without any beneficiation or mixing with the lower grade coals. In later period when the high quality coking coals exhaust, leaving the massive amount of lower quality coals could lead into huge disadvantages due to the inadequate coal quality to be exported.

One of the most suitable method to solve those issue was to increase properties of the low grade coal into high grade coal by beneficiation methods. Most common beneficiation method in the world is physical beneficiation method such as dense media separations, magnetic separations jigging and froth floatation etc. Physical beneficiation methods are always based on the physical properties of the coal such as mass, size, density and magnetism etc. By those physical beneficiation methods gangue could be separated from coal to a limited extend which result removal of ash content but those methods are less effective due to yield restrictions. Because main focus in every mining company is to have maximum yield at minimum process cost. In this case, chemical beneficiation methods are more effective than physical beneficiation methods. Because in chemical beneficiation methods, accurate separation between mineral components and coals are operated inside of the coals structure.

Main reason behind the wide spread of physical beneficiation is the sufficient knowledge and experience of many years of experts in the field of coal beneficiation plant. While in chemical beneficiation methods, due to the price of the process and other limitations experts started to get interested in the chemical beneficiation methods only around ten years from now on.

In chemical beneficiation methods to maximize the yield of the product at minimum process cost, selection of the exact reagent and chemical that is used for the particular coal deposit is a must. Thus in this thesis study, determination of the reagent and chemical based on the typical of minerals contents in the coal structure is studied due to great significance in the coal chemical beneficiation methods.

Coal with coking property but has high ash content was studied by using seven different chemical agents and alkali-acid leaching had the highest efficiency in removing inorganic minerals from coal matrix. Total 6 different chemical leaching was performed on the samples with 3 different durations with 3 different temperatures and with 2 different concentration of chemicals in 500 ml of glass reactor under ambient pressure.

By chemical beneficiation any desired ash content could be reached when the chemicals adjusted in the most suitable state with temperature, duration and chemical concentration, any desired ash content could be reached.

State of Art

1 Outlook of Coal deposits in Mongolia

Mongolia is a one of the natural resource rich developing country. Mongolian most of the imports consist from natural resources such as copper, gold, coal, silver, zinc and molybdenum etc., which are the pillar of Mongolian economy and one of the most dominant product from Mongolia is high quality coking coal.

Mongolian coal mining history is developed relatively later than the rest of the world. From 16th century in North America and from middle 17th century in Germany coal mining started commercially while only in early 20th century Mongolia started first coal mine. The very first mine was located in Nalaikh and opened in 1912 [2]. From then Mongolian, Russian, Eastern Europe and Western country researchers started intensify their studies on coal resources in Mongolia and discovered that there are more than 200 coal occurrences and deposits in Mongolia.

Mongolia has 152 billion tons [3] of coal conjectured reserve and has 2.7 billion tons of proven coal reserve in 2006[4]. From 2006 to 2016 in ten years, coal mining and production in Mongolia was increased five times from 7.8 Mt in 2006 [2] to 39 Mt in 2016 [World o] which shows high demand and significant of coal production by importing into Asian countries such as China, Japan, Korea, and Taiwan.

From the figure 1, you could see that 15 bituminous coal deposit, 4 subbituminous coal deposit and 28 lignite coal deposit in 2009. Coal quality in increases from Mongolian eastern provinces to Mongolian western provinces. Several coal deposits located in Mongolian central and northern provinces while in Mongolia central eastern provinces lignite coal deposits are densely populated. Thus from the densely populated coal-bearing provinces, Mongolian coal deposits divided into two main coal-bearing provinces which are Mongolian eastern provinces and Mongolian western provinces with total

Figure 1. Province: WM — Western Mongolian; EM — Eastern Mongolian; Basins: KHB — Kharkhiraa; MAB — Mongol–Altai; SGB — South Gobi; UHB — South Khangai; IBB — Ikh Bogd; ORB — Ongi river; CNB — Choir–Nyalga; CHB — Choibalsan; TAB — Tamsag; SHB — Sukhbaatar; EGB — East Gobi; CGB — Central Gobi basin; Areas: BUA — Bayan–Ulgii; TAA — Trans–Altai; OSA — Orkhon–Selenge; Coal deposits: 1 — Khushuut; 2 — Maanit; 3 — Khuren gol; 4 — Tsagaan gol; 5 — Zeegt; 6 — Khuden; 7 — Nuurst khotgor; 8 — Khartarvagatai; 9 — Rashaant; 10 — Olonbulag; 11 — Tsakhiurt Urt; 12 — Uvurchuluut; 13 — Alagtsakhir; 14 — Khotgor; 15 — Bayanteeg; 16 — Tsagaan–Ovoo; 17 — Nariin sukhait; 18 — Tavantolgoi; 19 — Mogoin gol; 20 — Ulaan–Ovoo; 21 — Shariin gol; 22 — Nalaikh; 23 — Baganuur; 24 — Maint; 25 — Tsaidam; 26 — Tugrug; 27 — Khumuult; 28 — Tsaidam nuur; 29 — Olongiin Ukhaa; 30 — Alagtogoo; 31 — Shivee-Ovoo; 32 — Ulaan nuur; 33 — Ikh Ulaannuur; 34 — Uvdugkhudag; 35 — Tevshiin gobi; 36 — Khulstnuur; 37 — Aduunchuluun; 38 — Utaat minjuur; 39 — Talbulag; 40 — Ulziit; 41 — Zuunbulag; 42 — Bulangiin khooloi; 43 — Bayantsogt; 44 — Taliin khudag; 45 — Nukhet; 46 — Khootiin khonkhor; 47 — Khamriin khural; 48 — Gurvantes

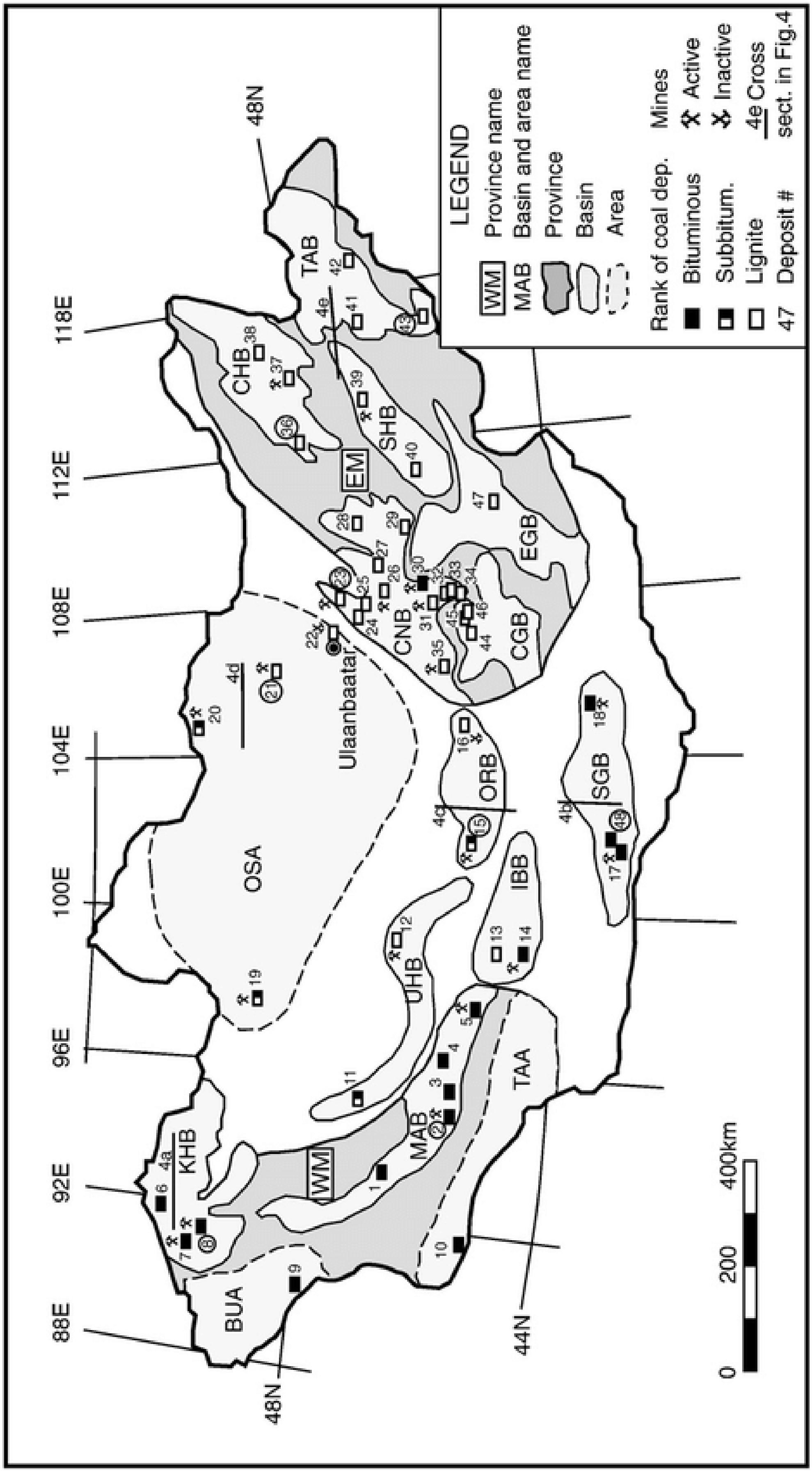


Figure 1 A location map of Mongolian coal-bearing provinces, basins and deposits [9]

twelve basins and three areas. eastern provinces and Mongolian western provinces with total twelve coal-bearing basins and coal-bearing three areas. Coal-bearing basins basically means the large area which consist of high qualified coal seams which have defined origin as from evolution of territorial tectonic structure. Coal-bearing area are similar to the coal-bearing basins but main difference is that origin of the coal-bearing area are unknown and coal seams in the area are seldom compared to the coal-bearing basins.

By Mongolian and Russian researchers with geological survey and prediction from fossils, the age of coal-bearing veins are identified. Altai group is believed that formed in Pennsyvanian thus named Penndylvanian Altai group in the Mongolian western province. [5] As for Zuunbayan group in Mongolia eastern province believed that formed in Aptain-Albain. [6]

In figure 2, there shows five main periods that coal-bearing veins are formed by tectonic plate movement of divergent related to extension of plates, convergent related to compression of plates and transform related to overlap of the rocks in Mongolia. In Carboniferious period Pennsylvanian coal-bearing veins took place in Mongolian western province around three hundred million years ago. Coals formed at late Permian period in the southern province on Mongolia gradually shifted to the eastern part of the Mongolia and distributed evenly except western province of Mongolia. In middle Jurassic period, coal formed by convergent movement of the plates located in western, southern, northern and eastern provinces of Mongolia. In early Cretaceous period, thick layer of coal, oil shale, oil and bitumen formed in southern valley of lakes, eastern province and Orkon-Selenge area of central and northern of Mongolia.

Thus the outlook of the Mongolian coal-bearing vein start from Pennsylvanian Altai group and continued with Upper Permian Tavantolgoi group, Lower-Middle Jurassic Jargalant, Bakhar, Saikhan formation and end with Zuunbayan group [2].

Pennsylvanian Altai group consists of Bottom, Middle and Top, three main formations with total 22 complex seams. Coals in areas of Trans-Altai and Bayan-Ulgii make the Bottom of Pennsylvanian Altai group while coals in the Mongol-Altai and Kharkhiraa basins make the Middle and Top formation of the Pennsylvanian Altai group.

Upper Permian Tavantolgoi group has several sub-coal-basins and deposits which is the largest coal reserve in Mongolia which makes around 5.6 billion tons. Upper Permian

Tavantolgoi group is also famous for containing almost all of the high grade coking coal in Mongolia.

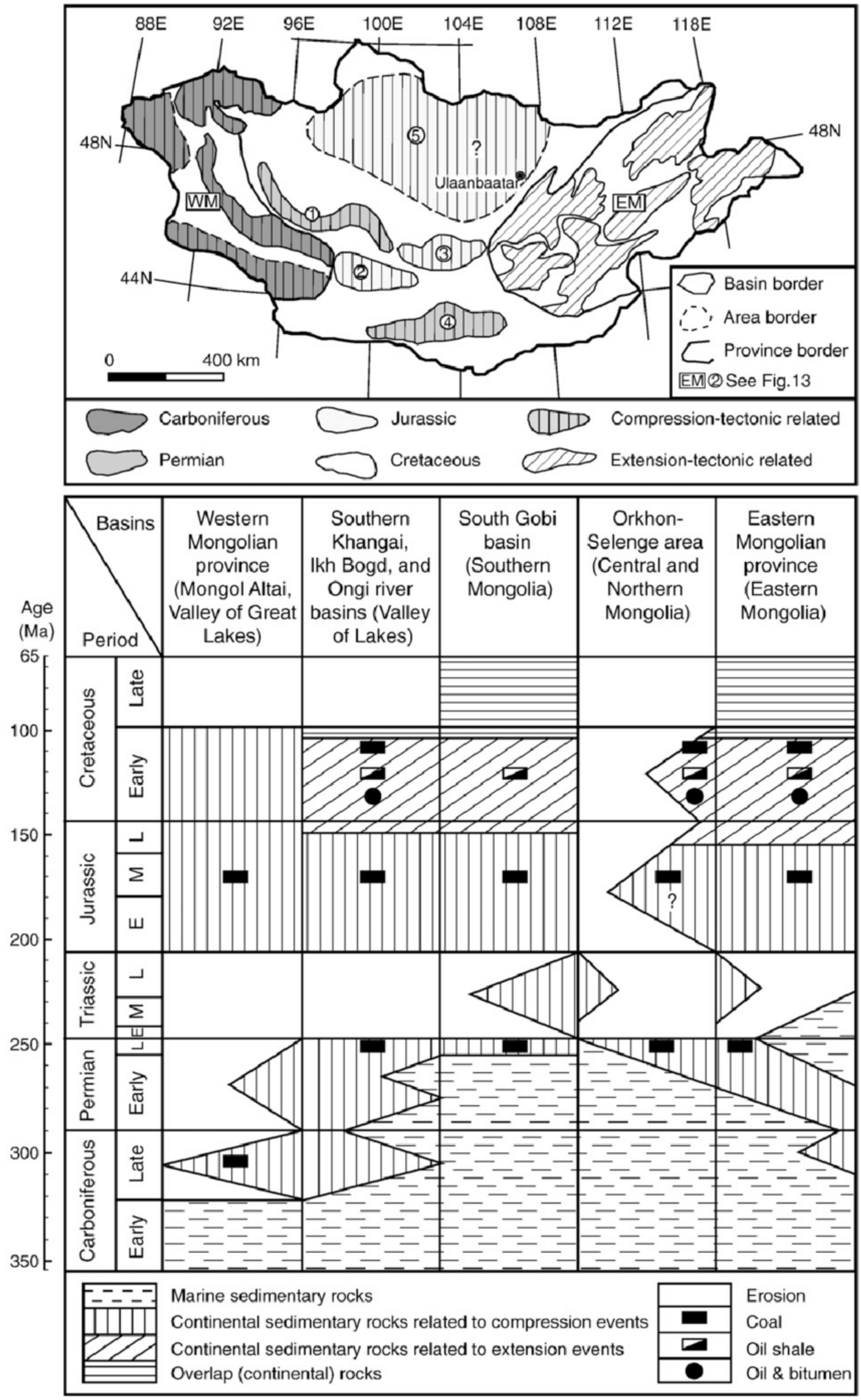


Figure 2 Summary of age and tectonic regime of coal-bearing strata in different parts in Mongolia [9]

From Khentii Range, Mongolian eastern province has mainly coal basins from Lower Cretaceous Zuunbayan volcano-sedimentary group and little bit amount from Lower-Middle Jurassic and Permian strata. Mongolian eastern province has the largest deposit of coal and oil shake-bearing which are six separate basins.

Compared to some southern coal-bearing basins such as South Govi and Orkhon-Selenge area coal which had moisture ranging from 0.5 to 2.3 wt.% with some the coal-bearing basins in the western Mongolia provinces had relatively lower moisture ranging from 1.1 to 4.7 wt.% but eastern Mongolian province coal-bearing basins had much higher moisture content ranging from 7.0 to 13.7 wt.%.

Similarly, volatile matter of the southern and western coal-bearing basins had relatively lower that the eastern coal-bearing basins. As for ash percentage of the coal western coal-bearing basins ranged from 11.6 to 33.2 wt.%, southern coal-bearing basins ranged from 11.2 to 25.1 wt.% while eastern coal-bearing basins ranged 10.2 to 28.5%.

From the characteristics of some coal deposits, western coal-bearing basins consists of bituminous coal with high to low volatile traits, southern coal-bearing basins characterized by bituminous coal with high to medium volatile traits and subbituminous coals and eastern coal-bearing basin predicted to be mainly lignite and subbituminous coal.

From figure 3 and figure 4, coals formed during Carboniferous period had characteristics of lower hydrogen while having lower to medium carbon content, medium volatile matter with the medium caloric value, very low to medium moisture with medium caloric value, lower sulphur content compared to other coal periods but had very high ash content which were two or three times higher than period coals.

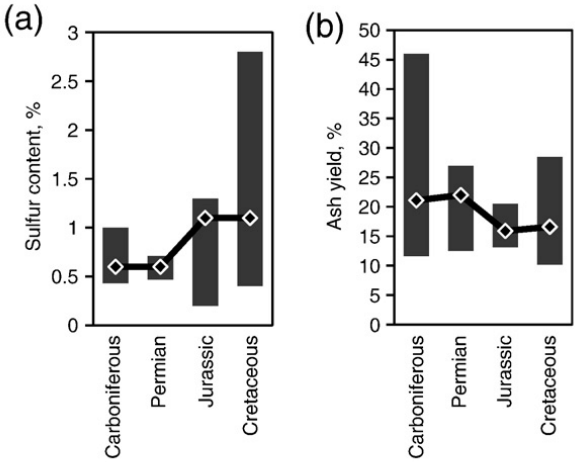


Figure 3 Coal characteristics by the period [2]

Coals formed during Permian period had characteristics of medium volatile matter with the relatively lower caloric value, very low moisture with low caloric value, lowest sulphur content and had lower ash content. Coals formed during Jurassic period had characteristics of medium to higher hydrogen content in medium carbon content, medium to higher volatile matter with the medium caloric value,

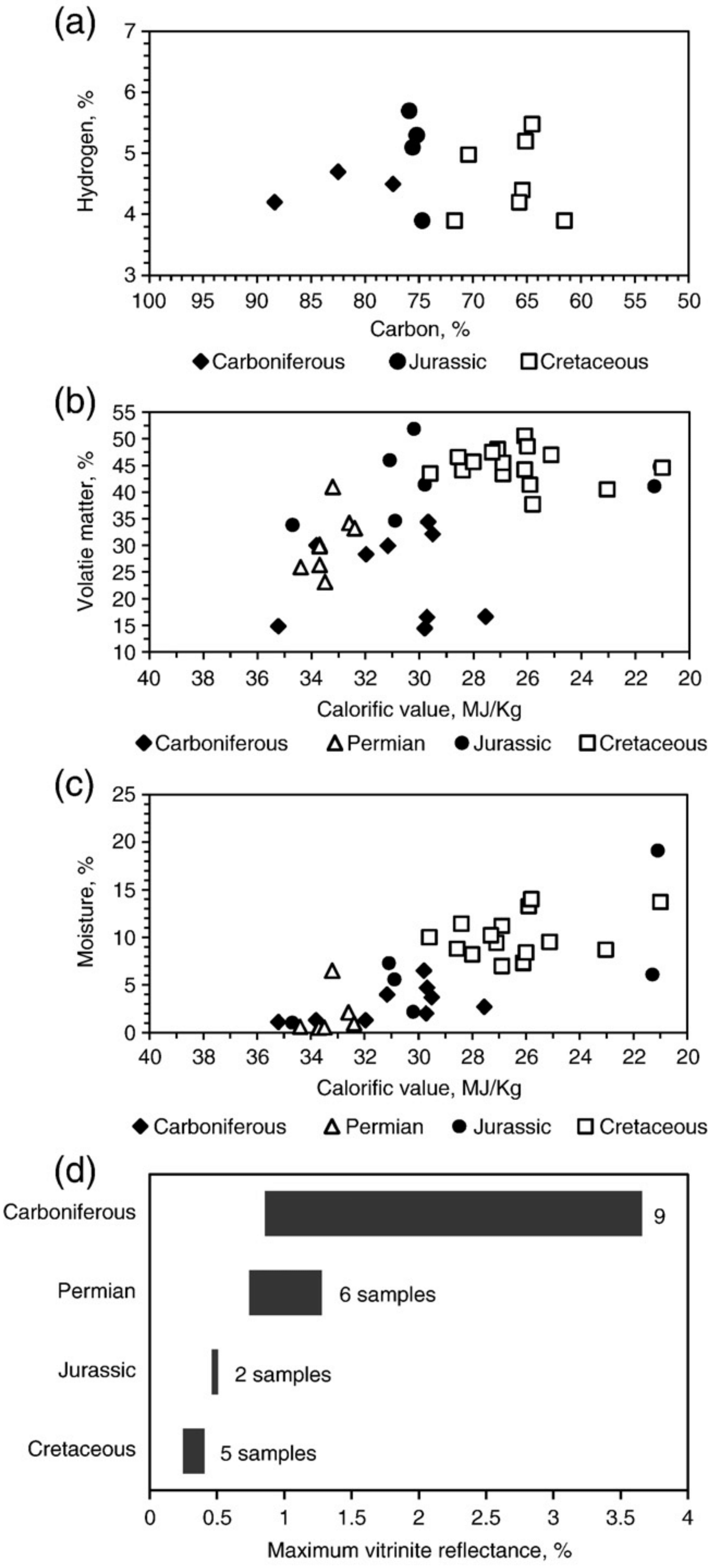


Figure 4 Coal characteristics by the period [2]

medium moisture with medium caloric value, medium sulphur content and had lowest ash content.

Coal formed during Cretaceous period had properties of the medium to higher hydrogen with higher carbon content, volatile matter, moisture, ash content compared to others and had highest sulphur content.

1.1.1 The coal-bearing upper Permian Tavantolgoi group

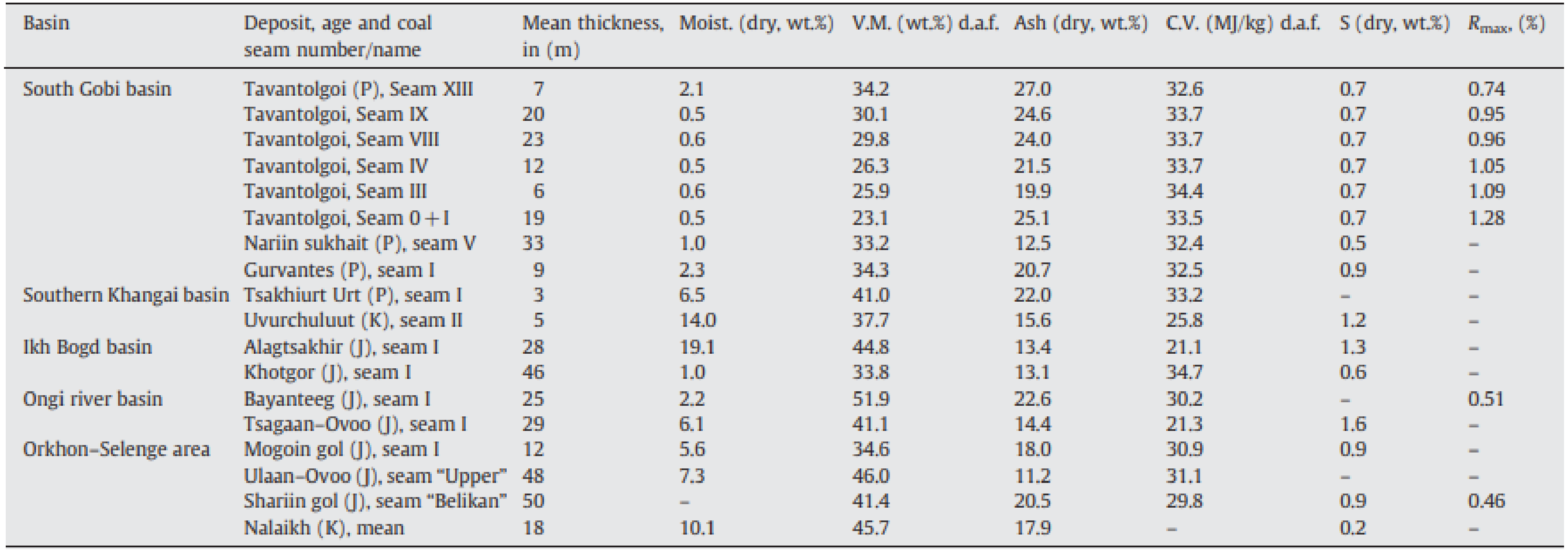
The coal-bearing upper Permian Tavantolgoi group locates in the southern Mongolia which covers 40 000 km^2. The group has 260 m to 1200 m thick lower-Multicolored formation, and 215 m to 1220 m thick upper-Coal-bearing formation. The lower-Multicolored formation rocks have red and brown color and consists of agglomerate with sandstone, gravel and siltstone layers. The upper-Coal-bearing formation has red, gray green, gray and brown in color and consist of siltstone, sandstone, veins of limestone with siderite. The overlaying Coal-bearing formation hosts fourteen individual coal seams and consists of shale, siltstone, sandstone and coal measures with thin gravel. Conglomerate, coaly shale and rare limestone layers [2]. Coal-bearing formation of upper Permian Tavantolgoi group's settling time considered from the flora, similar to the Angaraland's central region. [7]

In figure 5, the coal quality analysis is done in some of the deposits at South Gobi basin is shown. From Tavantolgoi's total fourteen seam the coals from seam XIII, seam IX, seam VIII, seam IX, seam III and seam 0+1 and Naliin Sukhait seam V are characterized.

In figure 6, petrographic studies show that Tavantolgoi seam coals macerals are mainly consist of Vitrinite around 55.4 to 78 vol.% m.m.f., Inertinite 19 to 43.6 vol.% m.m.f. and very small amount of Liptinite 1 to 7 vol.% m.m.f.

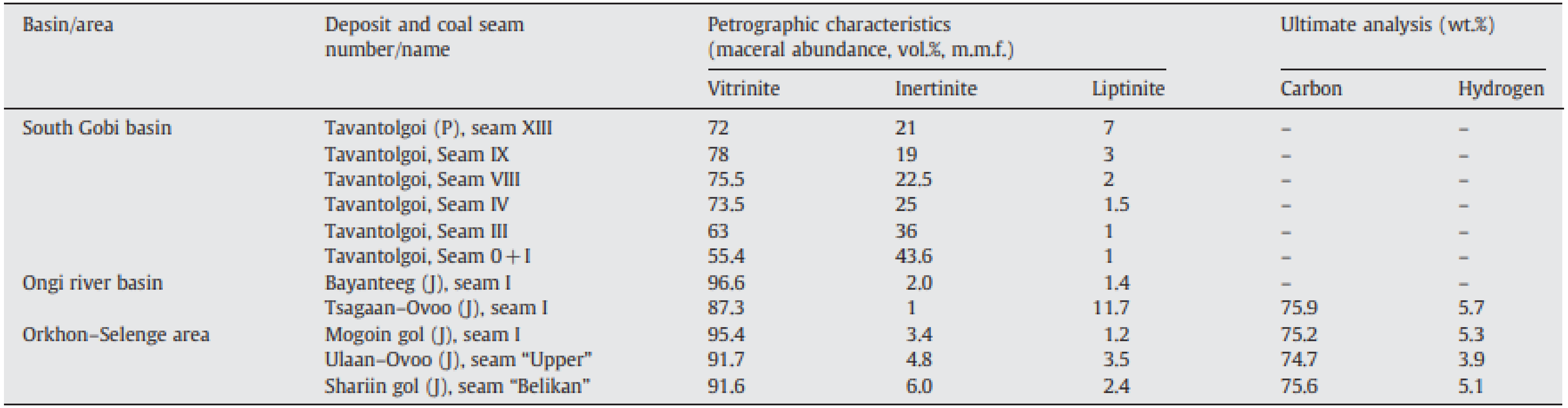
Moisture content of Tavantolgoi seams ranged from 0.5 to 2.1 wt.%, 23.1 to 34.2 wt.% volatile matter, 19.9 to 27 wt.% ash, 32.6 to 34.4 MJ/kg caloric value and 0.7 wt.% sulphur while Nariin sukhait seam V had 1.0 wt.%, 33.2 wt.% volatile matter, 12.5 wt.% ash, 32.4 MJ/kg caloric value and 0.5 wt.% sulphur.

Those properties show the rank of the coals from Tavantolgoi and Nariin sukhait seams are high to medium volatile high grade bituminous coal.



Basin	Deposit, age and coal seam number/name	Mean thickness, in (m)	Moist. (dry, wt.%)	V.M. (wt.%) d.a.f.	Ash (dry, wt.%)	C.V. (MJ/kg) d.a.f.	S (dry, wt.%)	R_{max}, (%)
South Gobi basin	Tavantolgoi (P), Seam XIII	7	2.1	34.2	27.0	32.6	0.7	0.74
	Tavantolgoi, Seam IX	20	0.5	30.1	24.6	33.7	0.7	0.95
	Tavantolgoi, Seam VIII	23	0.6	29.8	24.0	33.7	0.7	0.96
	Tavantolgoi, Seam IV	12	0.5	26.3	21.5	33.7	0.7	1.05
	Tavantolgoi, Seam III	6	0.6	25.9	19.9	34.4	0.7	1.09
	Tavantolgoi, Seam 0+I	19	0.5	23.1	25.1	33.5	0.7	1.28
	Nariin sukhait (P), seam V	33	1.0	33.2	12.5	32.4	0.5	–
	Gurvantes (P), seam I	9	2.3	34.3	20.7	32.5	0.9	–
Southern Khangai basin	Tsakhiurt Urt (P), seam I	3	6.5	41.0	22.0	33.2	–	–
	Uvurchuluut (K), seam II	5	14.0	37.7	15.6	25.8	1.2	–
Ikh Bogd basin	Alagtsakhir (J), seam I	28	19.1	44.8	13.4	21.1	1.3	–
	Khotgor (J), seam I	46	1.0	33.8	13.1	34.7	0.6	–
Ongi river basin	Bayanteeg (J), seam I	25	2.2	51.9	22.6	30.2	–	0.51
	Tsagaan-Ovoo (J), seam I	29	6.1	41.1	14.4	21.3	1.6	–
Orkhon-Selenge area	Mogoin gol (J), seam I	12	5.6	34.6	18.0	30.9	0.9	–
	Ulaan-Ovoo (J), seam "Upper"	48	7.3	46.0	11.2	31.1	–	–
	Shariin gol (J), seam "Belikan"	50	–	41.4	20.5	29.8	0.9	0.46
	Nalaikh (K), mean	18	10.1	45.7	17.9	–	0.2	–

Figure 5 Coal quality of Southern province basins [2]



Basin/area	Deposit and coal seam number/name	Petrographic characteristics (maceral abundance, vol.%, m.m.f.)			Ultimate analysis (wt.%)	
		Vitrinite	Inertinite	Liptinite	Carbon	Hydrogen
South Gobi basin	Tavantolgoi (P), seam XIII	72	21	7	–	–
	Tavantolgoi, Seam IX	78	19	3	–	–
	Tavantolgoi, Seam VIII	75.5	22.5	2	–	–
	Tavantolgoi, Seam IV	73.5	25	1.5	–	–
	Tavantolgoi, Seam III	63	36	1	–	–
	Tavantolgoi, Seam 0+I	55.4	43.6	1	–	–
Ongi river basin	Bayanteeg (J), seam I	96.6	2.0	1.4	–	–
	Tsagaan-Ovoo (J), seam I	87.3	1	11.7	75.9	5.7
Orkhon-Selenge area	Mogoin gol (J), seam I	95.4	3.4	1.2	75.2	5.3
	Ulaan-Ovoo (J), seam "Upper"	91.7	4.8	3.5	74.7	3.9
	Shariin gol (J), seam "Belikan"	91.6	6.0	2.4	75.6	5.1

Figure 6 Elemental and petrographical composition of southern Province Basins [2]

The South Gobi basin contains high grade bituminous coking coal in Mongolia and has largest coal deposit Tavantolgoi in Mongolia with resources of 5.6 billion tons. One quarter of Tavantolgoi reserve is estimated to be high grade bituminous coking coal. Tavantogloi consist of Tsankhi, Ukhaa Khudag, Bor tolgoi, Borteed, and Southernwest and Eastern coalfield sections. Ukhaa Khudag section is mined by Mongolian Mining Corporation and 6% of the coal deposits and all other coalfield sections are owned and managed by Erdenes MGL.

Mongolian Mining Corporation has total three coal processing plant which has capacity of processing 5 million tons of coal per plant. Mongolian Mining Corporation operates open pit surface mine and produces coking coal with 8 to 10 wt.% of ash content for import after physical beneficiation and mixing of the coal.

The Ukhaa Khudag section is mined by Mongolian Mining Corporation has 581 million tons of coal reserve and has three main sections which are fresh - non-faulted zone, affected - faulted zone and zero sections - O group seams. Affected – faulted zone’s coals are degraded by water, wind or ice causing the change in property of the coal. Fresh – non-faulted zone’s coals are high grade coals with coking property and zero section – O group seam has lower quality coals.

There are coal seams that has coking property but has high ash and sulphur content which makes the coal seam unqualified to export as a high qualified coking coal. By physical beneficiation method, lowering the ash and sulphur content of the coal was less effective and economically inefficient. Thus in the thesis work, this coal seam is selected as a sample for further study by applying the chemical beneficiation method.

2 Fundamentals of Coal

2.1.1 General Concept of Coal origin

Formation of coal from peat residues from higher plants in moist environment with accumulation of organic matter and with the process of decomposition of an organic matter. Accumulated peat is buried over time is converted into coal over a long time by heat and pressure and the oldest coal-bearing seams have 290 to 360 million years' history with them. Coal quality depend on its age.

The temperature is very important parameter during the formation of coal because only in certain temperature certain type of coal could form. Coking coal is created at an average temperature of 300° C while 500° C temperature is required to form anthracite during the process.

2.1.2 Characteristics of Coal

Coal is a sedimentary rock and their main types are anthracite, bituminous, sub-bituminous and lignite. Type of coals differs from each other by their properties for example their content of carbon. Brown coal (lignite) is the coal with the lowest content of carbon with high moisture content while bituminous hard coal and anthracite has highest content of carbon and caloric value.

Highest rank coal is meta-anthracite (metamorphosed anthracite) sublevel of the anthracite. Anthracite coal is shiny black in colour, hard, brittle, which contains a high percentage of solid carbon (around 86 to 98 wt.%) and very low percentage of volatile substances (around 14 to 2 wt.%).

Bituminous coals are middle grade coal which has shiny dark or dark brown colour with carbon content around 85 wt.% and has 12 wt.% ash content.

Sub-Bituminous coals are higher caloric value than lignite and looks dull black to dark brown in colour with high moisture (around 10 to 45 wt.%) and up to 45 wt.% volatile matter content.

Lignite is also known as a brown coal due to its brownish black colour with highest moisture content and lowest carbon content.

Coals with high carbon content and with less inorganic minerals are favoured due to its environmental impact and due to its coking properties.

2.1.3 Metallurgical coal and Thermal coal

Metallurgical coal is mainly bituminous and anthracite mainly used to produce coke during the process of steel making. Metallurgical coal or coking coal has ability to produce low density, strong coke and during coking the coal expands in volume aside from having low ash, moisture and sulphur content. Metallurgical coal has four main types hard coking coal, medium coking coal, semi-soft coking coal and pulverized coal for injection coal.

Thermal coal is mainly sub-bituminous and lignite generally used for power generation and to produce electricity. The key difference of thermal coal is, it does not have ability to produce coke even though having high caloric value.

Due to the difference in usage metallurgical and thermal coal price is very different from each other. Coking coal is around three times more expensive than the thermal coal.

2.1.4 Coal composition

Coals consist of three different categories of substances which are organic matter, inorganic matter and fluids.

Organic carbonaceous matters present in coal are called macerals. There are three different macerals Vitrinite, Inertinite and Liptinite. They differ from each other by their origin and Vitrinites are derived from cell walls of the plants and most abundant compared to other two. As for Inertinite, it derived from peat swamp and robustly degraded plants and Liptinite is derived from waxy part of the plants and usually makes up 5 to 15 % of the coal. From the figure 6, you could see that most of the macerals from Tavan Tolgoi seams are Vitrinite and 19 to 43.6 % of Inertinite and very small amount 1 to 7 % is Liptinite.

Inorganic minerals in the coals are mainly consists of clays, pyrite, marcasite and quartz that formed during coalification or carried by water and wind activity in the coal structure. Inorganic minerals are the main source of ash and volatile matter.

Lastly the fluids between the coal structure consist mainly from moisture and methane.

The main representative of inorganic mineral, “clay” consist mainly from silica, pyrite and calcite. Inorganic minerals could have presence of all elements in the earth but the main components of minerals are C, H, O, N, and S that are bounded into to coal structure. Inorganic minerals have non-combustible property which causes the ash formations.

Coal ash consists mainly from quartz and clay minerals with silicon, aluminium, iron oxides and other oxides, such as, calcium, magnesium, sodium, potassium, titanium. Other trace elements are strontium, Nickel, zinc, cadmium, mercury, lead, antimony, uranium, Chrome, Vanadium, etc. [link3]

Reduction of ash content in coal has several significant advantages. Because ash presence in the coal lowers the calorific value of the coal and increases cost of transportation. In addition, the presence of silicates and alumina silicates significantly lead into slag formation and contamination in the furnaces, heaters and turbines which reduces greatly life time of the equipment by corrosion and erosion (link 2). Presence of As, Se, Hg, B and cynates in coal ash could lead into serious health problems when the toxic elements released in the atmosphere. Therefore, ash removal has great importance in the long run during the coal processing.

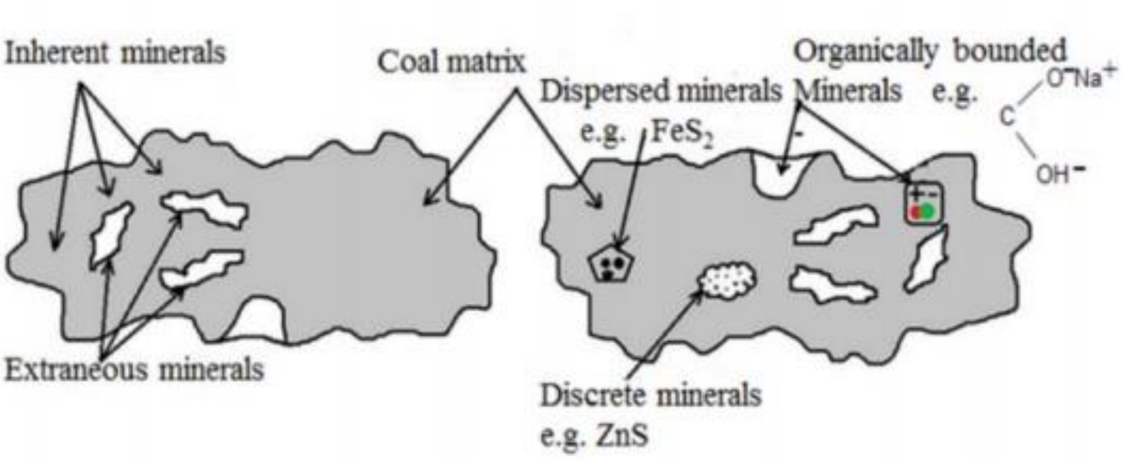


Figure 7 Modes of occurrence of minerals and other constituents in coal [8]

Figure 7 shows that mineral matter exist in coal matrix in three different ways, dispersed minerals, discrete minerals and organically bounded minerals. Example of dispersed mineral is FeS_2, discrete mineral is ZnS and organically bounded mineral is CHO_2Na.

Mineral matters are also classified by Speight (link1) as extraneous mineral matter or inherent mineral matter based on how they formed in the coal as shown in figure 7.

Inherent mineral matter is associated with the coal structure during a coal formation meaning as organically bounded minerals. The inherent mineral matters could have been present in the coal forming plant or could be present due to external sides when the coal is forming.

Extraneous mineral matter does not bound into coal matrix and they are carried by the wind, water flow or any other ways to stuck in the coal beds which eventually become inorganic overburden during mining operation and transportation which could be present in the coal as dispersed and discrete minerals [9].

3 Introduction to the beneficiation process

Metallurgical coal used in iron, cement and steel industry specially coking coal has direct relationship with steel making which has a high demand in the industry thus makes coking coal especially valuable.

But as time goes mineable hard coal reserves are depleting around the world and mining coal in the deeper seams from underground mine become more and more difficult which makes it economically inefficient [10] compared to the low grade coal which are plenty in the abundance but has limited usages due to its undesirable characteristics and high content of inorganic minerals which are the main source of ash. At the same time until we find new renewable energy source which could replace coal as an energy supply, we would be using coal due to the importance of mining as source of economic growth in the developing countries.

For example, as mentioned above in the deposit of Ukhaa Hudag section, there are coals with coking property but has high ash and sulphur content. Thus limiting the coal potential to be exported as a metallurgical coal if the ash and sulphur content could be lowered into standard range of those coal seams could be exported as a coking coal.

From here beneficiation of low grade coal to turn the low grade coal into upgraded high grade coal starts playing big role. It is said that by using cheap inorganic acids, demineralisation and desulfurization could be achieved as high as 90% and more [9].

There are main three different technologies in coal beneficiation, physical, chemical and biological. Main upgrading from coal beneficiation is to separate the inorganic mineral matter from organic carbonaceous matter in coal matrix as much as possible to reduce the ash or S from its content with maximum yield. All the mineral matter in coal is not ash, residue of both organic and inorganic parts of coal which are changing chemically under combustion process.

3.1.1 Physical and Biological beneficiation process

Physical processing is most well-known and commercially used in all over the world. This processing based on the coal and its mineral's physical properties like weight, density and surface properties. Physical processing could separate the extraneous minerals from coal but unable to separate inherent mineral which makes physical processing inefficient to separate the sulphur or finely disperse minerals bound to the structure of coal. Physical processing is the most common way to treat the coal around the world while being expensive.

Biological treatment has potential to remove both extraneous and inherent minerals from coal but the process very slow thus requires time.

3.1.2 Chemical beneficiation process

The chemical leaching is faster and could clean the coal up to 90% by separating the minerals from the coal structure thus making the chemical processing a best way to process the coal from minerals [10]. In the last few decades many paper and experiments regarding to the coal processing are made which shows the trend of the future beneficiation technology.

Chemical beneficiation has a long history and it's reported that coal chemical processing is performed as early from World War II in Germany to make ultra clean coal (UCC) [11]. It is said that chemical beneficiation of UCC is exhaustive, dangerous and costly. UCC's ash percentage could be lowered as low as 0.82% but this treatment effects coal structure like caloric value would be lowered, or it affects other properties of the coal. UCC does not used for heating propose due to its high cost due. UCC requires excessive amount of acids and duration of the process is long thus this method is not commercial. Thus this method is only for coal that is used to make aromatic chemicals, electrode, carbon anodes, active carbon and carbon nanotubes.

Chemical beneficiation method has not been employed commercially due to its cost from the reagents. In our case we are not aiming to produce UCC with ash percentage lower than 1%. Also our coal sample's ash value is relatively low around 20-30% and our target value is 8-10% which gives us the advantage of lowering the usage of reagents which has direct relationship with the cost of the process. Thus I believe that we could make the treatment simple as possible and efficient as possible to have economical advantage.

There are many types of reagent in the chemical processing and there are many experiments done with many different acids and alkalis. To choose the right reagent for the experiment, to know the typical of minerals are in the coal is most important. In the previous studies it is said that in coal structure there are mainly silica, quartz, pyrite, calcite, dolomite, siderite and ankerite etc. [10]. Coal structure should be studied by using laboratory analysis such as ICO-AES, MS etc. By depending on the minerals contained in the coal, we should do further investigation for possible chemicals suitable to use. For example, in one [5] study silica and aluminum oxide took nearly 90% of the ash in the coal and they used sodium hydroxide as alkali and hydrogen chloride as acid to do an alkali-acid leaching and removed 99% of the silica and 80% alumina bearing minerals. Its reported that they removed the almost 60% of the spend acid for further use [4] in this study more than 90% of the ash forming compounds were from silica, aluminum oxide and iron oxide and they used different types of acids to do the acidic leaching and the most suitable acid was 25% HF at 80 Celsius with operation time of 240 min.

In this process it's reported that mainly the leaching time temperature and size of the feed and to use how much amount of the chemical effects to the yield mostly. Thus we expected to do analysis on the size and temperature of the chemical beneficiation with respect to time. And the demineralization performances (DPs) shows how much ash is reduced at the reaction and it is calculated with the ash concentration result. Following formula is for the calculating demineralization performance:

$$DP,\% = \frac{(Feed\ Ash,\% - Product\ Ash,\%)}{(Feed\ Ash,\%)} * 100$$

In Mehtap Paul et al.'s research study (2006) [12] thirteen Turkish coals with different characteristics were selected but they concentrated mainly on acid leaching on their ashes and only several of the coals characteristics were within our interest. Coal from Kurahya-Tuncbilek was mainly metal rich lignite while coal from Istanbul-Agacli had laminate structure with high content of vitrinites, with low content of sulphur and ash. The coal from Kahraman Maras-Afsin-Elbistan-Kislakoy which represents the dirtiest and lowest ranked coals in Turkey with low heating value but has a huge reserve thus most of the electricity in Turkey is provided by this coal. Lastly coal from Beypazari was contaminated by underground water and had high content of trace elements and sulphur. The method used in this paper was acid leaching of coal and coal ash. Dry coal was mixed with deionized water (1:10 solid: liquid, by weight) and the mixture was stirred overnight (>12 h). Then at 25 C 1 M of H2SO4 was added into the mixture till the pH of the solution reached 1.0 if necessary 1 M of H2SO4 was added subsequently to maintain the pH 1.0. To curve the time dependence, the leaching period was 60 min, 1, 2, 4, 8, 16 and 32 h. After leaching the effluent of the solution was separated from the solid and analysed with ICP-ARS/MS/SMS. Results were compared with study of maximum extraction with concentrations after 10 days of continuous leaching in sulphuric acid at pH 1.0. They said that whole coal consumed the acids very rapidly in the first 12h and slowed down afterwards. They explained the rapid acid consumption may due to carbonate dissolution and possibly from the rapid exchange at the surfaces and the consumption reaction decreased with exchange at inner structure of the coal. Particles size of coals ranged between 250-1000 um and they showed increase in leaching with decreasing particle size.

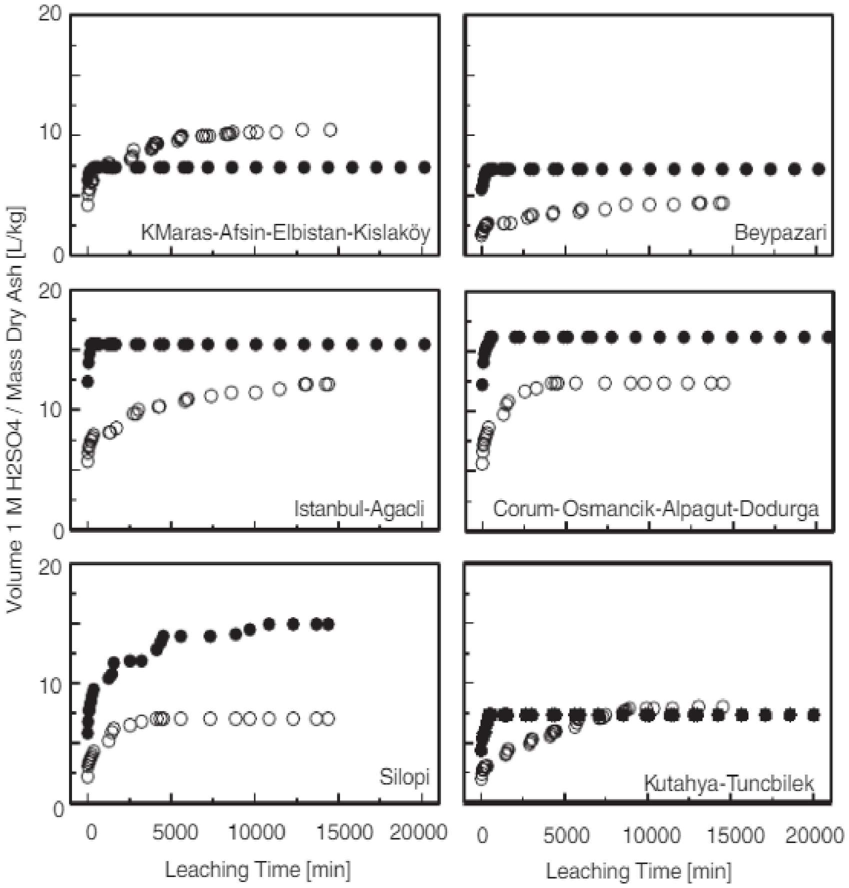


Figure 8 Acid consumption during coal-ash leaching. The open dots show the accumulated volume of 1 M H2SO4 to maintain pH 1.0. Initial solid/ liquid ratio 1:10. The filled dots show the equivalent amount for ground whole coals. The values for the whole coals have been divided by the fraction non-combustible material ("ash" part) in the coal. [6]

From the figure 8, we could see that coal from KMaras-Afsin-Elbistan-Kislakoy which represents the dirtiest and lowest ranked coal, coal from Beypazari which has high content of trace element and sulphur, and coal from Kurahya-Tuncbilekhad which is metal rich lighnite are consumed relatively lower amount of acid compared to coal from Istanbul-Agacli which has high content of vitrinites. Also we could see that KMaras-Afsin-Elbistan-Kislakoy's coal ash had high consumption acid per litre and coal ash from Beypazari had lowest consumption of acid from the figure 1. They also highlighted that cadmium is typically extracted more than 90% in most ashes but less in whole coals and apart from clay minerals, organic occurrences of chromium in whole coals may associated with other oxides due to heat during combustion. From the results after 10h of leaching of coal gave nearly complete removal of acid-consuming parts of coals. They suggested continued test for bench or pilot plant operations for feasible process designs and investigation of heating value and the quality of the coal after leaching is necessary.

4 Methodology

4.1.1 Material

Coal sample was selected from Mongolian the largest coal deposit, Tavantolgoi's Ukhaa Hudag section which located in the South Govi basin. Ukhaa Hudag section of Tavantolgoi is mined and processed by Mongolian Mining Corporation. Mongolian Mining Corporation uses a surface mining technique, open-pit mining. Mongolian Mining Corporation has three coal processing plants with capacity of producing total 15 million tons of coal and Mongolian Mining Corporation is only mining company which processes the coals and exports after mixing the coal seams to produce desired product.

Coal sample represents coals with coking property but has high ash and sulphur content. Characteristics and reaction of coal sample is studied with chemical beneficiation method to reduce ash and other inorganic minerals from coal matrix. If the experiments would be successful, the coal seam would be upgraded into coking coal to exported as a metallurgical coal if the ash and sulphur content could be lowered into standard range.

4.1.2 Sample Preparation

Sample preparation step during the experimental work very important because laboratory sample taken from large amount of coal should be able to represent whole coal reserve. 80 to 85% of accuracy of the experiment result only depends on sample preparation shows the importance of standard sample preparation. Without question laboratory sample should have same characteristics from where, when, who took the sample. For example, 200 g of sample represents 120 000-ton coal reserve and lastly only 2 gr of the sample used in ash analysis. Another important aspect is parallel analysis and analysis standard should have maintained standard.

To have high accuracy, smaller particle size has advantages over the bigger the particle size. Because when the particles size is bigger, the more sample material is required.

Samples in the experiment need -50 mm, -10 mm, -1.2 mm of particle size. Thus the first step in the sample preparation process would be crushing the coal sample in jaw crusher. After jaw crusher our particle sizes should have enough fineness. But if the particle size is not satisfactory using fine grinder is suggested.

A standard sieving technique is done in crushed sample to do size analysis. After separation of sample into required particle sizes, systematic sampling with riffle splitter would start.

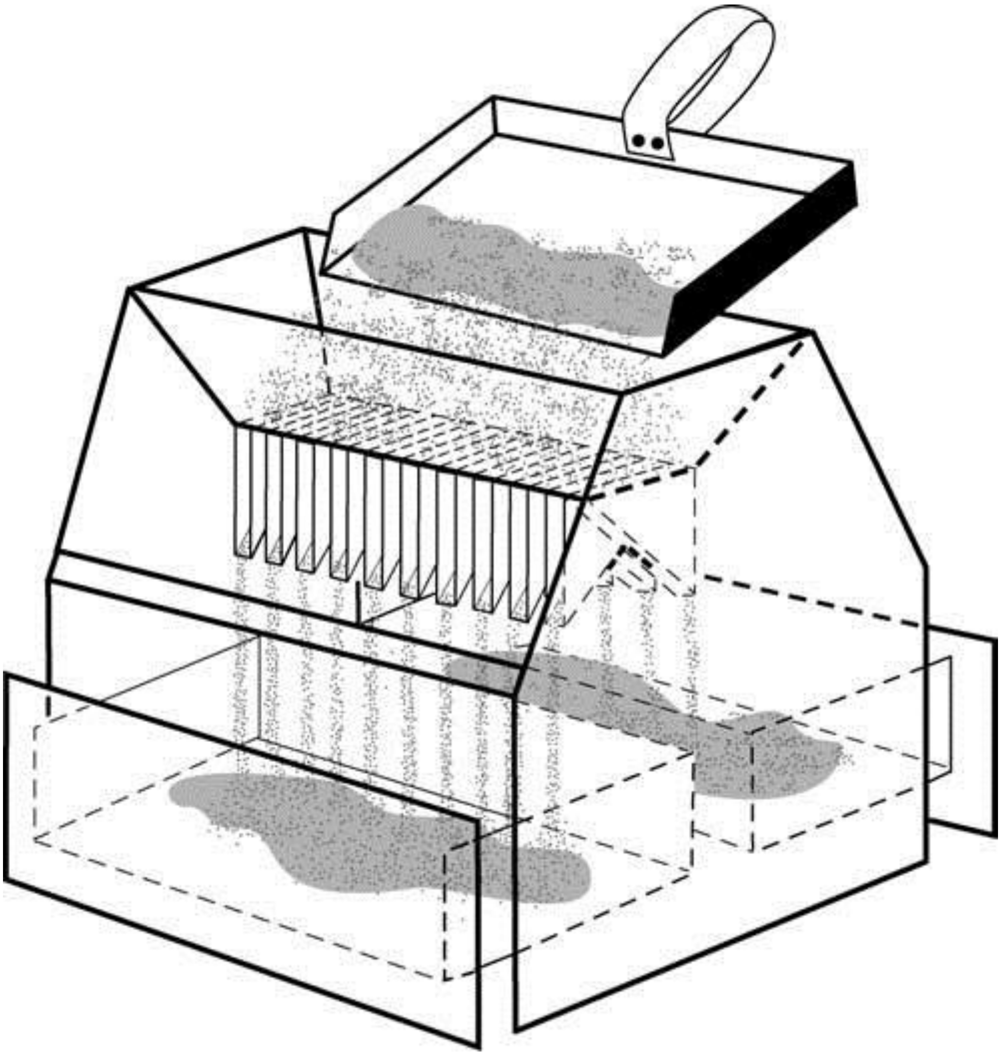


Figure 9 Riffle Splitter [13]

In the figure 9, riffle splitter is shown.

Procedure of the riffle splitter

1. Feed the splitter.
2. Riffle splitter divides the sample into two trays
3. Discard one tray
4. Feed the splitter again with the sample in the other tray
5. Repeat the process two more times.

4.1.3 Equipment and Chemicals

Equipment used in the experimental work:

- Jaw crusher /Jaw crusher is used in the first size reduction process/
- Fine grinder /Fine grinder is used in the second size reduction process/
- Laboratory sieve shaker /Sieve shaker is used for the separation of sample by size/
- Riffle splitter /Riffle splitter is used for sample preparation/
- Beaker 200 ml /Beaker for the chemicals/
- Glass reactor 500 ml /In the glass reactor chemical leaching reaction would take place/
- Magnetic-stirring hot plate /Magnetic stirring hot plate is for the heating and stirring of the mixture during the reaction/
- Magnetic stirrer /Magnetic stirring used to stir the mixture/
- Filter paper /Filter paper is used for the filtering of the solid from the mixture/
- Drying oven /Drying oven should be used to dry the solid material/
- Spatula /Spatula used for measuring the coal sample/
- Laboratory plastic dishes /Plastic dishes used for measuring the coal sample/
- Personal protective equipment

Chemicals:

- Hydrofluoric Acid
- Hydrochloric Acid
- Sodium Hydroxide
- Nitric Acid
- Sulfuric Acid
- Distilled water

4.1.4 Experimental Method

Laboratory experiments are performed on coal sample with four different particle size. Chemical leaching was performed with 4 different strong acids (hydrofluoric acid, hydro chloric acid, nitric acid and sulfuric acid) and one strong base (sodium hydroxide). Single acid washing was performed with 4 acids and 1 base and 2 alkali-acid leaching was performed sodium hydroxide as base followed by sulfuric acid and hydrofluoric acid.

Table 1 Experimental Plan

Particle size	**Chemical**		**Time**		**Temperature**		**Acid Concentration**
on a raw coal size	Hydrofluoric Acid	HF	40 min	50 min	60C	80C	25%
	Hydrochloric Acid	HCL					
	Sodium Hydroxide	NaOH					
	Nitric Acid	HNO3					
	Sulfuric Acid	H2SO4					
	Sulfuric Acid after Sodium Hydroxide	NaOH + H2SO4					
	Hydrofluoric Acid after Sodium Hydroxide	NaOH + HF					
-50mm	Hydrofluoric Acid	HF	40 min	50 min	60C	80C	25%
	Hydrochloric Acid	HCL					
	Sodium Hydroxide	NaOH					
	Nitric Acid	HNO3					
	Sulfuric Acid	H2SO4					
	Sulfuric Acid after Sodium Hydroxide	NaOH + H2SO4					
	Hydrofluoric Acid after Sodium Hydroxide	NaOH + HF					
-10mm	Hydrofluoric Acid	HF	40 min	50 min	60C	80C	25%
	Hydrochloric Acid	HCL					
	Sodium Hydroxide	NaOH					
	Nitric Acid	HNO3					
	Sulfuric Acid	H2SO4					
	Sulfuric Acid after Sodium Hydroxide	NaOH + H2SO4					
	Hydrofluoric Acid after Sodium Hydroxide	NaOH + HF					
-1,2mm	Hydrofluoric Acid	HF	40 min	50 min	60C	80C	25%
	Hydrochloric Acid	HCL					
	Sodium Hydroxide	NaOH					
	Nitric Acid	HNO3					
	Sulfuric Acid	H2SO4					
	Sulfuric Acid after Sodium Hydroxide	NaOH + H2SO4					
	Hydrofluoric Acid after Sodium Hydroxide	NaOH + HF					

Total 6 different chemical leaching was performed on the samples with 3 different durations with 3 different temperatures and with 2 different concentration of chemicals in 500 ml of glass reactor under ambient pressure according to the table 1.

Magnetic-stirring hotplate should be provided on samples with particle size of -50 mm, -10 mm and -1.2 mm with stirring fixed at 200 rpm. Hotplate without stirring is provided on sample with the raw coal.

A 100 g coal sample would be used in each test (Before 20 gr of coal planned to use in the experimental work but due to the need of the analysis of the coal, amount of the coal sample is added). Then pure water and acid were added according to the concentration as the total volume of solution would be 300 ml.

For example, first test would have 100 g coal sample with -1.2 mm particle size leached by 50 ml of hydrofluoric acid diluted with 150 ml of distilled water at 60° C under ambient pressure.

After 80 min, by a filter paper the solid–liquid mixture obtained as the result have filtered and solids remained in the paper should be washed with water. After drying the sample for 12 h in a drying oven 105° C laboratory analysis should be performed to get the results.

Figure, shows the process flow sheet of the single step leaching and alkali-acid leaching procedure. Single step acid or alkali leaching has 5 main units, size reduction, sieving, acid or alkali leaching, filtration and washing followed by drying process. Alkali-acid leaching has 7 main units, size reduction, sieving, alkali leaching, filtration and washing followed by acid leaching, filtration and washing finished with drying process.

4.1.5 Analysis

Coal samples should have analyzed by basic analysis (ash, volatile matter, moisture) of coal and with X-ray florescence method inorganic minerals (silica, alumina, iron, calcium, magnesium etc.) should be analyzed before.

All laboratory samples after experiments be analyzed by basic analysis of coal and with X-ray florescence and if necessary Perkin Elmer Inductively coupled plasma mass spectroscopy (ICP-MS) analysis should be done in the liquid sample.

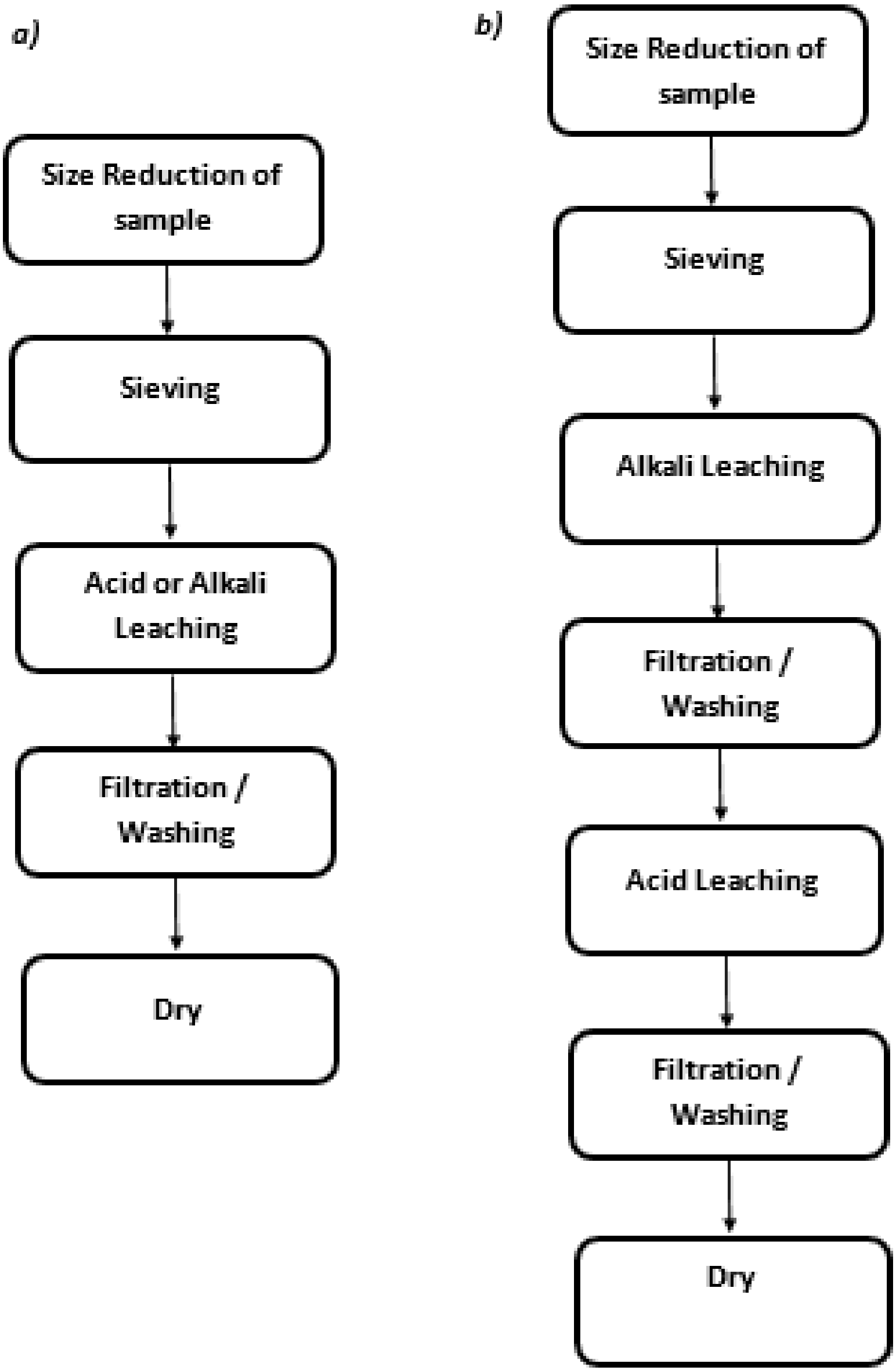


Figure 10. Process Flow sheet a) Single acid or single base leaching b) Alkali-acid leaching

4.1.6 Health and Safety

In this thesis study, several strong acids and base used which is essential to have introduced with the safety and hazard analysis.

Hydrofluoric Acid: Hydrofluoric acid is one of the most dangerous acids because acid is not only corrosive and toxic when the acid make contact with the skin the fluoride ion penetrates and causes skin tissue destruction. Unless neutralizes the hydrofluoric acid with the calcium gluconate antidote acid continue for days and result could be severe even death is possible. Also hydrofluoric acid vapors cause ocular irritation when inhaled. [14]

Thus, when working with the hydrofluoric acid, proper personal protective equipment and laboratory hood must be functioning properly. Goggles, face shield, acid resistant apron, long pants and sleeves, closed tor shoes and gloves are required as a personal protective equipment.

When spilled dilute hydrofluoric acid with a sodium bicarbonate solution and neutralize the acid when dispose the acid.

Figure 10[15]

Figure 11 [16]

Hydrochloric Acid: Hydrochloric acid is corrosive hazardous liquid. Personal protective equipment consists of vapor respirator, rubber gloves, boots, full body suit and face shield. Working environment must have access to an eye flush station. When disposing, hydrochloric acid must be neutralized with base. [22]

Figure 12[15]

Nitric Acid: One of the extremely corrosive acid and when inhaled it could cause severe harm due to rapid chemical burn. Personal protective equipment consists of safety glasses, vapor respirator, rubber gloves, boots, full body suit and face shield. Working environment must have access to an eye flush station. When disposing, nitric acid local environmental control regulation must be followed. [18]

Figure 13 [17]

Sulfuric Acid: One of the extremely corrosive acid and when inhaled it could cause severe harm due to rapid chemical burn. Personal protective equipment consists of safety glasses, vapor respirator, rubber gloves, boots, full body suit and face shield. Working environment must have access to an eye flush station. When disposing, sulfuric acid must be neutralized with base. [24]

Figure 14[15]

Sodium Hydroxide: Sodium hydroxide is very corrosive and odorless base. Personal protective equipment consists of safety glasses, vapor respirator, rubber gloves, boots, full body suit and face shield. Working environment must have access to an eye flush station. When disposing, sodium hydroxide must be neutralized with acid. [26]

Figure 15[15]

5 Result

5.1.1 Feed coal characteristics

Table 2 Properties of Feed Coal

Proximate Analysis	
Ash (%)	29
Moist. (%)	3
C.V (MJ/kg)	7000
S (wt.%)	0,6
V.M (wt.%)	24
Ash Composition %	
SiO2	11,3
Al2O3	5
P	0,11
Fe	0,96
Alkali (Na2O + K2O)	0.49

Coal samples have assumed that has 29 wt.% ash because maximum of the untreated coal ash of Ukhaa Hudag section was reported to be. Coal sample had 24 wt.% volatile matter which is average volatile matter amount in the untreated coal. Similarly coal sample had 3 wt.% moisture and 0.6 wt.% Sulphur content in average. Caloric value has taken relatively higher which is 9480 MJ/kg because the coal supposed to have coking property. Proximate analysis should be done in standard laboratory to later to check the accuracy.

For the ash composition of coal, X-ray florescence method inorganic minerals should be performed. Assumption had ash composed of 11.3% of SiO_2, 5% of Al_2O_3, 0.11% of phosphorous, 0.96% of iron and 0.49% of alkali based on the common minerals in the coal composition.

5.1.2 Ash percentage and composition data after leaching

The Table 3, Table 4 and Table 5 shows the result of the ash reduction from coal leaching. Assumption was made that hypotheses of my thesis work is reached with coal chemical leaching. If variables increase results precision and dependency would show more understandable. The Table 6 shows the ash composition after coal leaching.

Table 3 Result of Ash Assumpsion with Raw Coal Size

Size of the particle	Temperature	Time	Chemical	Ash (wt.%)
on a raw coal size	60 C	40min	HF	15,69
			HCL	17,04
			NaOH	17,83
			HNO3	16,94
			H2SO4	17,12
			NaOH + H2SO4	14,94
			NaOH + HF	14,03
	60 C	50min	HF	15,18
			HCL	16,89
			NaOH	17,64
			HNO3	16,71
			H2SO4	16,94
			NaOH + H2SO4	14,82
			NaOH + HF	13,84
	80 C	40min	HF	14,47
			HCL	16,81
			NaOH	17,69
			HNO3	16,72
			H2SO4	16,09
			NaOH + H2SO4	14,75
			NaOH + HF	14,01
	80 C	50min	HF	14,29
			HCL	16,81
			NaOH	17,82
			HNO3	16,68
			H2SO4	15,85
			NaOH + H2SO4	14,62
			NaOH + HF	13,94

In table 3, results of ash weight percentage chemical leaching on raw sample coal without any size reduction. Two variables were time and temperature, at temperature of 80 C and 60 C two different time duration were 40 min and 50 min with 4 different acids and 1 base to present seven different chemical leaching with the variables to make 28 experiment and 28 different results.

Table 4 Result of Ash Assumption with -50 mm Particle Size

Size of the particle	**Temperature**	**Time**	**Chemical**	**Ash (wt.%)**
-50 mm	60 C	40min	HF	11,69
			HCL	15,04
			NaOH	17,34
			HNO3	15,13
			H2SO4	16,27
			NaOH + H2SO4	8,49
			NaOH + HF	8,16
	60 C	50min	HF	11,28
			HCL	14,81
			NaOH	17,18
			HNO3	14,75
			H2SO4	16,08
			NaOH + H2SO4	8,02
			NaOH + HF	7,94
	80 C	40min	HF	10,49
			HCL	14,53
			NaOH	16,45
			HNO3	14,92
			H2SO4	15,48
			NaOH + H2SO4	7,61
			NaOH + HF	7,41
	80 C	50min	HF	10,29
			HCL	14,17
			NaOH	16,31
			HNO3	14,59
			H2SO4	15,16
			NaOH + H2SO4	7,21
			NaOH + HF	7,06

In Table 4, results of ash weight percentage from chemical leaching on sample coal size of -50 mm with the size reduction. Similarly, two variables were time and temperature, at temperature of 80 C and 60 C two different time duration were 40 min and 50 min with 4 different acids and 1 base to present seven different chemical leaching with each variables to make 28 experiment and 28 different results.

Table 5 Result of Ash Assumption with -1.2 mm Particle Size

Size of the particle	**Temperature**	**Time**	**Chemical**	**Ash (wt.%)**
-1,2 mm	60 C	40min	HF	9,14
			HCL	14,85
			NaOH	15,95
			HNO3	13,45
			H2SO4	14,75
			NaOH + H2SO4	7,35
			NaOH + HF	7,18
	60 C	50min	HF	9,06
			HCL	14,25
			NaOH	15,73
			HNO3	13,29
			H2SO4	14,35
			NaOH + H2SO4	7,15
			NaOH + HF	7,08
	80 C	40min	HF	8,45
			HCL	13,48
			NaOH	14,95
			HNO3	12,47
			H2SO4	13,85
			NaOH + H2SO4	6,04
			NaOH + HF	5,99
	80 C	50min	HF	8,24
			HCL	13,29
			NaOH	14,45
			HNO3	12,27
			H2SO4	13,48
			NaOH + H2SO4	5,75
			NaOH + HF	5,09

In table 5, results of ash weight percentage from chemical leaching on sample coal size of -1.2 mm with the size reduction. Similarly, two variables were time and temperature, at temperature of 80 C and 60 C two different time duration were 40 min and 50 min with 4 different acids and 1 base to present seven different chemical leaching with each variables to make 28 experiment and 28 different results.

Table 6 Result of Ash Composition Assumption with -1.2 mm Particle Size

Size of the particle	**Temperature**	**Time**	**Chemical**	**Ash (wt.%)**	**SiO2**	**Al2O3**	**P**	**Fe**
-1,2 mm	60 C	40min	NaOH	15,95	10,09	4,81	0,1	0,95
			NaOH + H2SO4	7,35	5,02	1,94	0,01	0,38
			NaOH + HF	7,18	5,12	1,67	0,02	0,37
	60 C	50min	NaOH	15,73	10,23	4,47	0,09	0,94
			NaOH + H2SO4	7,15	5,22	1,59	0,02	0,32
			NaOH + HF	7,08	4,44	2,34	0,01	0,29
	80 C	40min	NaOH	14,95	10,53	3,39	0,08	0,95
			NaOH + H2SO4	6,04	4,32	1,41	0,02	0,29
			NaOH + HF	5,99	4,32	1,38	0,03	0,26
	80 C	50min	NaOH	14,45	9,23	4,21	0,07	0,94
			NaOH + H2SO4	5,75	4,08	1,39	0,01	0,27
			NaOH + HF	5,09	3,54	1,27	0,03	0,25

In table 6, results of ash composition after chemical leaching on sample coal size of -1.2 mm with the size reduction. Similarly, two variables were time and temperature, at temperature of 80 C and 60 C two different time duration were 40 min and 50 min with 4 different acids and 1 base to present seven different chemical leaching with each variables to make result on each mineral in the coal composition.

6 Discussion and Conclusion

6.1.1 Variables in the experimental study

Data derived from experimental work and coal basic data before the study are provided in section five. Ash content of feed coal had 29 wt.% in the coal structure and this number is considered lower value compared to the Indian and Turkish coal which has ash content more that 30 to 47 wt.% [18].

Lower ash content of sample coal has great significance due to reduced amount of the chemical in the beneficiation process. The coals with very high content of ash used around 25 % concentrated chemicals thus it would be logical to use 10 % concentrated chemicals for the lower ash content coals. This was the reason behind concentration of the chemicals content are selected as a 10 %.

Coal ash composed mainly from silica, alumina, phosphorous, iron, alkali and other trace elements. Silica and alumina took almost 70 percentage of the ash composition and they are minerals that are hard to eliminate because of its position in the coal structure. Only by chemical beneficiation method silica and alumina could be removed defiantly with lowest price because if physical beneficiation method is used coal size should be into too small parts. If size of the processed coal is too small eventually there would be many issues and mass losses related to the process method and economically not efficient.

The target value of the experimental result in ash was 8 to 10 wt.% of the coal which are very optimal to reach by leaching process. Even only eliminating the silica or 50% of silica and alumina without processing other minerals in the coal, target of the experiment could be reached.

Selection of the chemical is based on the minerals in the coal structure and by concentrating on the silica and alumina, chemicals could be experimental in the first stage.

Another big aspect always needed to be consider is coking property of the coal. By chemical beneficiation the coal structure could be affected which could lead into reduction of carbon, caloric value lowering and swelling index could be lowered etc. Thus to prevent from the loss is coking property selection of the chemical accurate. Too strong acid or base could lead into great damage in the coal structure but main chemicals of the chemical beneficiation are always strong acids or base. Due to that, selection of the duration of the leaching was taken relatively short 40 min to 50 min per laboratory experiment.

Temperature and pressure had great influence in any chemical reaction which accelerates the reaction rate of the system. In laboratory scale study ambient pressure is taken due to the restrictions and temperature was chosen as 60 C and 80 C due to safety measures in the chemical laboratory. But finding the approximate temperature for the highest reaction rate temperature was taken as a variable.

Thus temperature, duration and chemical used in the experiment was main three variables in the study.

6.1.2 Data analysis

From the data on the section five, ash reduction on the coal sample with raw coal size. This was expected result because of the interaction between coal matrix and acid and base was minimized even though the coal is porous matter. As you can see from the data, lower the particle size higher the reduction of ash content.

The temperature of the 60 C and 80 C unexpectedly did not have great impact on the ash reduction degree. But it was due to the temperature range of the reaction thus in the future experimental work having more temperature variable are encouraged.

Duration of the reaction had direct relationship with the degree of ash reduction could be seen from the figures. Thus smallest possible size with the optimized temperature with the sufficient duration for the chemical beneficiation method is motivated with the experimental data.

Most of the strong acids excluding hydrofluoric acid shoved very similar ash reduction degree.

Leaching of sodium hydroxide showed almost no difference during the leaching of coal sample. The reason behind that was sodium hydroxide reacts with silica to produce insoluble salt as shown in reaction equation 1 to 3 below. [18]

$$SiO_2 + 2NaOH = Na_2SiO_3 + H_2O \qquad (1)$$

$$Al_2O_3 + 2NaOH = 2Na_2AlO_2 + H_2O \qquad (2)$$

$$2Na_2AlO_2 + Na_2SiO_3 + 3H_2O = [Na_8(AlO_2)_2(SiO_2)_3(OH)_6] \qquad (3)$$

Thus after leaching with acid after base leaching was far more effective than other stepwise leaching by following equation 4.

$$[Na_8(AlO_2)_2(SiO_2)_3(OH)_6] + 26HCL = 8NaCl + 2AlCl_3 + 3SiCl_4 + 16H_2O \qquad (4)$$

But always remember that reduction of the ash content is not only point of the study. Reducing the ash content while preserving coking property of the coal should be kept in mind.

In alkali-acid leaching method, sodium hydroxide used as a base and two different acids, sulphuric acid and hydrofluoric acid used as an acid on the (-1.2 mm particle size) coal sample.

In the first part of the alkali-acid leaching experiment, sodium hydroxide and sulphuric acid used on the coal sample in the study as shown in figure 7 and 8.

Effect of alkali leached coal was very low but with increased time and temperature

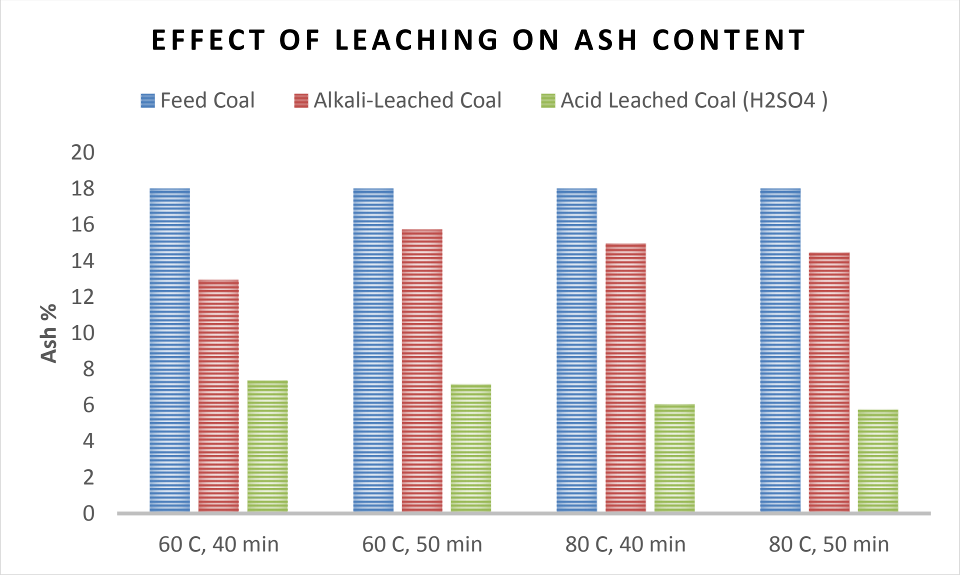


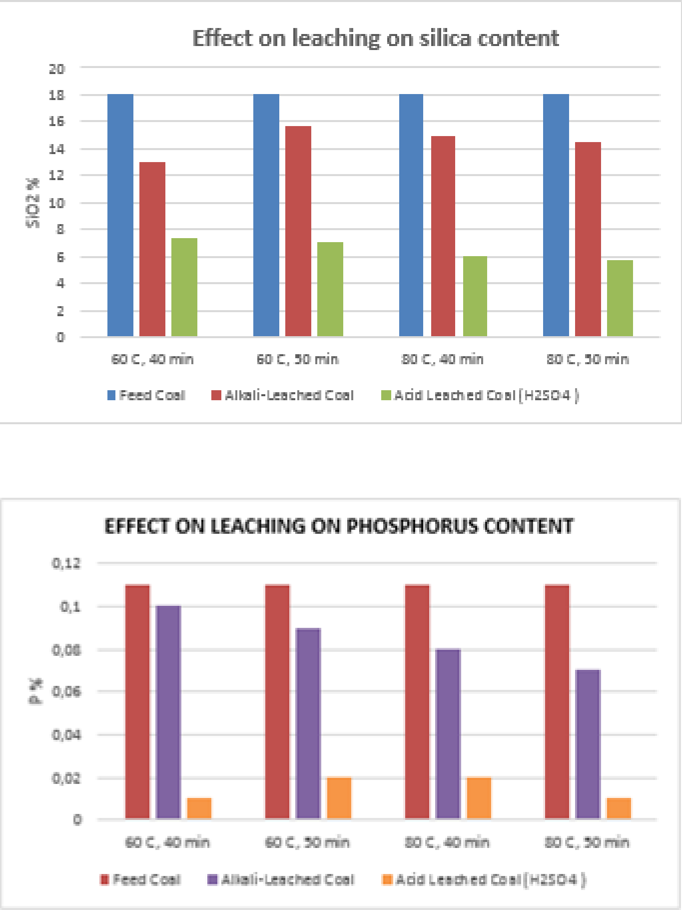
Figure 16 Effect of leaching on ash content

ability to reduce ash content is increased. But still, alkali leached coal did not have the ability to reduce more than 25 present. But after acid leaching step there has significant reduction in the ash content of the coal sample.

In the figure 8, shows how does the minerals are reduced with changing temperature and reaction duration.

Most reduced component of ash was phosphorus content and the other three had similar result. In alkali leaching of the first stage iron content almost remained same, and only lowered after acid leaching. Another unusual result was from alumina content in the temperature with 80 C and duration of 40 min. Alumina content increased while it should be decreased. This error may could have been caused by laboratory analysis error or systematic error.

Figure 17 Effect of leaching on ash composition



Next part of the alkali-acid leaching experiment had sodium hydroxide as a base and hydrofluoric acid as aa acid used in the coal experiment as shown in figure 7 and 8.

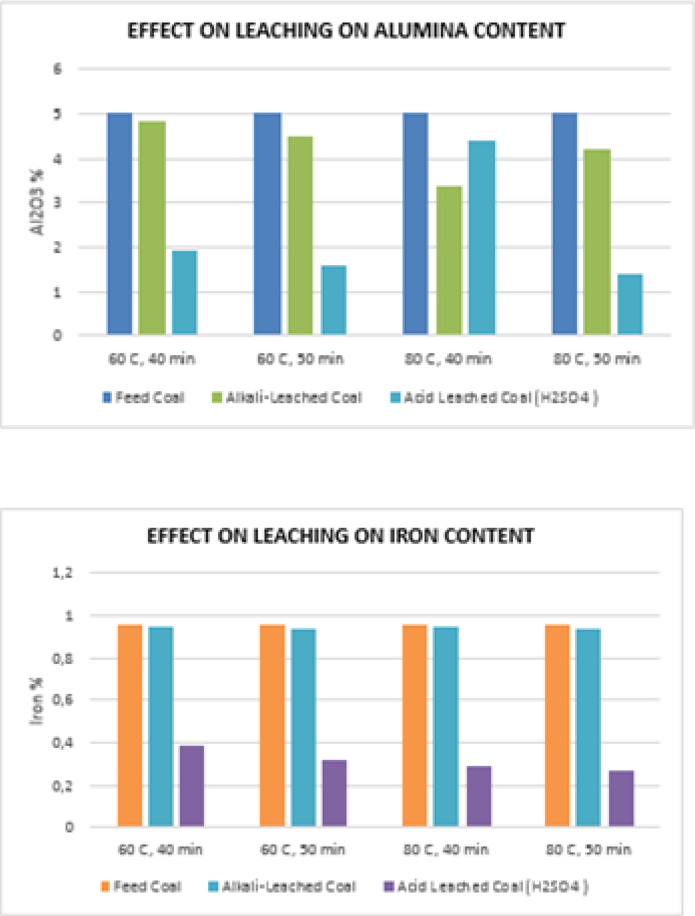


Figure 18 Effect of leaching on ash composition

Effect of hydrochloric acid was far more effective than other acids in lowering ash content. With the alkali-acid step the content of the ash reached at its lowest point.

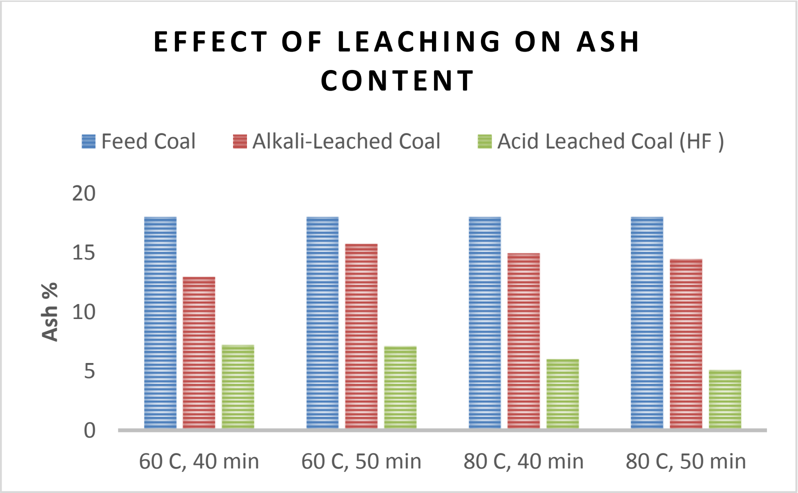


Figure 19 Effect of leaching on ash content

6.1.3 Future Research Needs

More experimental works and large scale of study is encouraged because result from the predicted data shows positive and approachable. Ukhaa Hudag sections', coal seam with cocking property but high ash content could be processed by chemical beneficiation method to reach low ash content with cocking property. When the chemicals adjusted in the most suitable state with temperature, duration and chemical concentration, any desired ash content could be reached.

Future research needed to be done in large scale study which could lead more for the opportunities for increasing the reserve of coking coal which has high demand in the industry. Increase of coking coal reserve is profitable because of the upgradation of low grade coal into high grade coal, if the results show positive values.

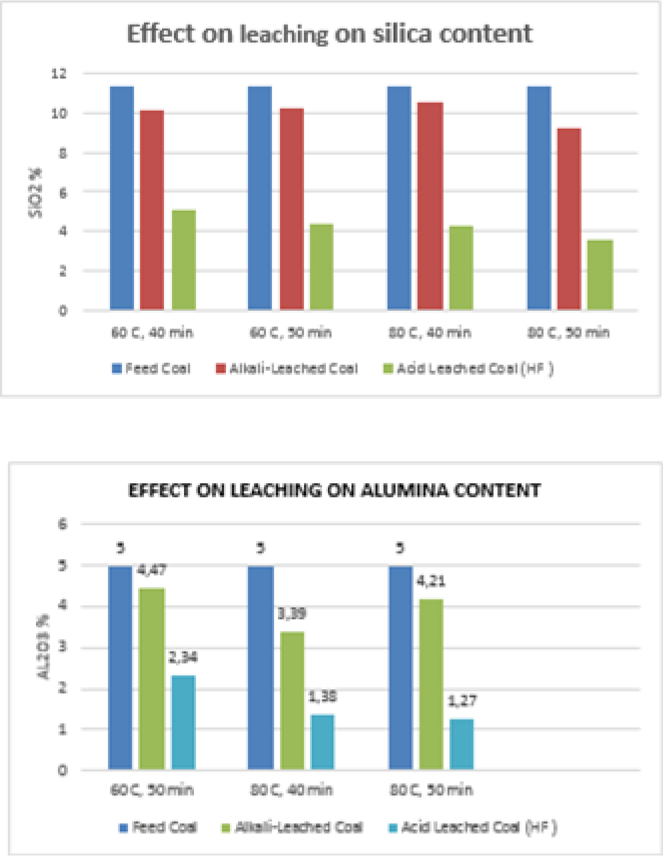


Figure 20 Effect of leaching on ash content

In the future, experimental works with more variables with time, temperature and concentration of chemical could lead into more fruitful and satisfactory result. Also question “How does real experimental results differ from predicted experimental results?” could be answered by comparing the real data with the predicted data.

Figure 21 Effect of leaching on ash content

6.1.4 Conclusion

Chemical beneficiation method is efficient than the physical defecation method due to its working principle. Chemical beneficiation method could reach into the coal matrix and dissipates the inorganic minerals while physical beneficiation method would require too small size distribution of coal to process. Coal with coking property but has high ash content was studied by using seven different chemical agents and alkali-acid leaching had the highest efficiency in removing inorganic minerals from coal matrix. From the variables, during the experiment higher temperature with longer duration time reaction could reach higher removal of ash concentration. By chemical beneficiation any desired ash content could be reached when the chemicals adjusted in the most suitable state with temperature, duration and chemical concentration, any desired ash content could be reached.

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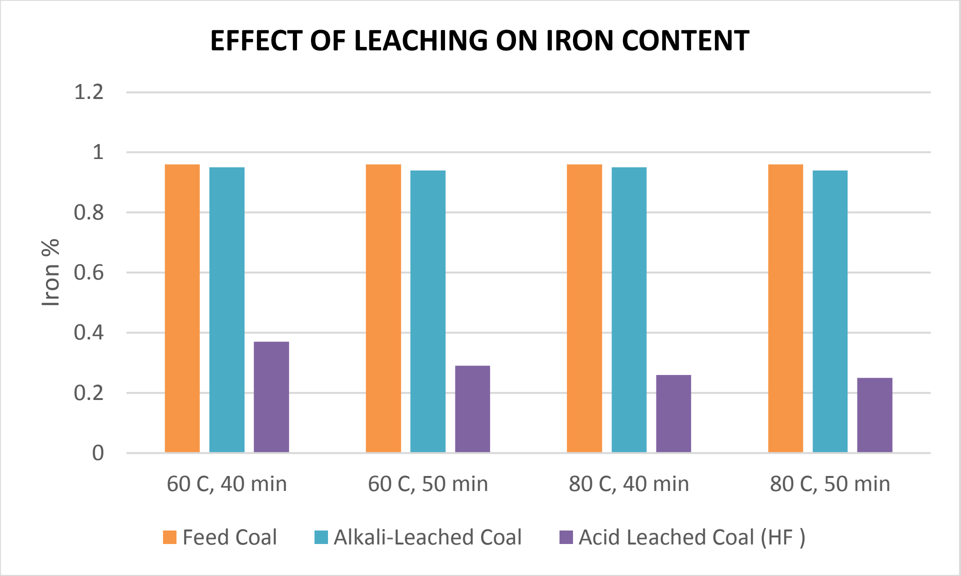
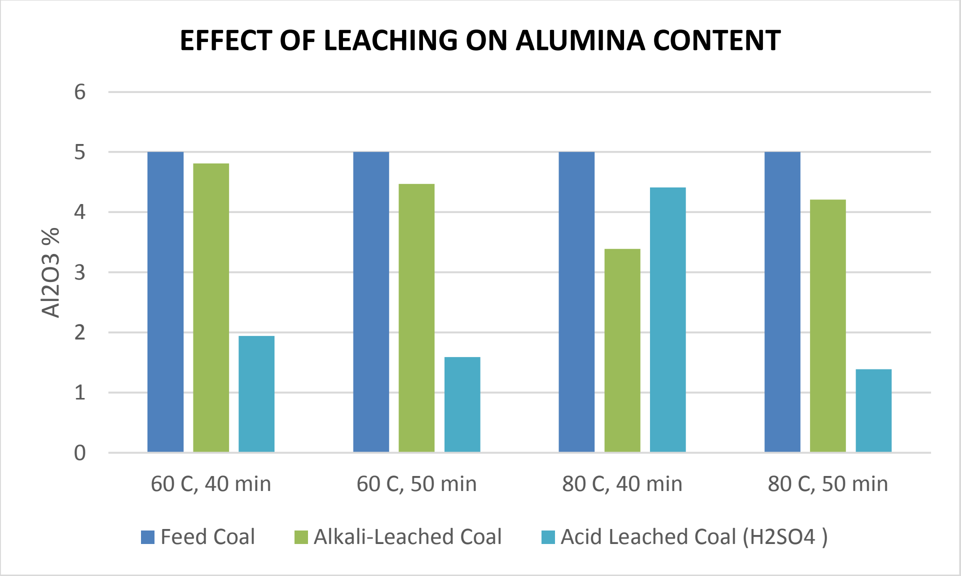
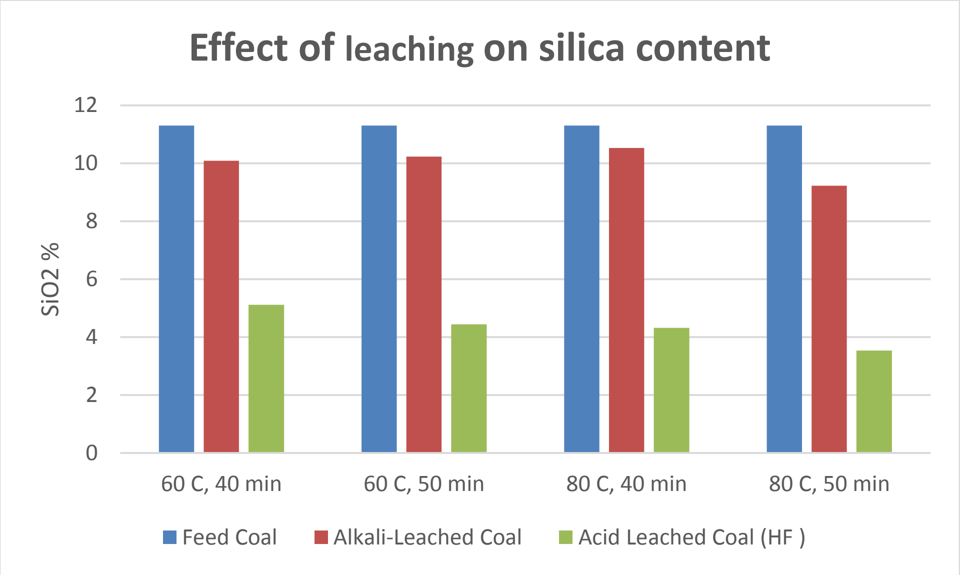
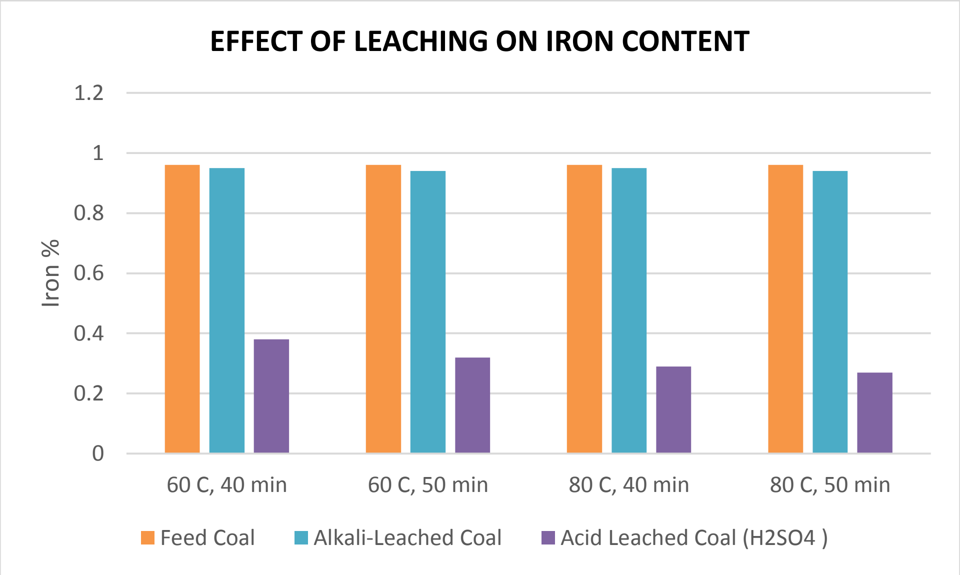
8 Appendix:


EFFECT OF LEACHING ON IRON CONTENT
Iron %
1.2
1
0.8
0.6
0.4
0.2
0
60 C, 40 min
60 C, 50 min
80 C, 40 min
80 C, 50 min
Feed Coal
Alkali-Leached Coal
Acid Leached Coal (HF)


EFFECT OF LEACHING ON ALUMINA CONTENT
Al2O3 %
6
5
4
3
2
1
0
60 C, 40 min
60 C, 50 min
80 C, 40 min
80 C, 50 min
Feed Coal
Alkali-Leached Coal
Acid Leached Coal (H2SO4)


Effect of leaching on silica content
SiO2 %
12
10
8
6
4
2
0
60 C, 40 min
60 C, 50 min
80 C, 40 min
80 C, 50 min
Feed Coal
Alkali-Leached Coal
Acid Leached Coal (HF)


EFFECT OF LEACHING ON IRON CONTENT
Iron %
1.2
1
0.8
0.6
0.4
0.2
0
60 C, 40 min
60 C, 50 min
80 C, 40 min
80 C, 50 min
Feed Coal
Alkali-Leached Coal
Acid Leached Coal (H2SO4)