GERMAN - MONGOLIAN INSTITUTE
FOR RESOURCES AND TECHNOLOGY

# FROTH FLOTATION BEHAVIOR OF COKING COAL IN TAVAN TOLGOI DEPOSIT

## Froth Flotation Chemicals Comparison

**Bachelor Thesis**

by

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# Statutory Declaration

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Independently and without undue external help. I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

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# 1. CHAPTER ONE INTRODUCTION

## 1.1. Introduction

Coal has traditionally been treated by gravity separation techniques, most suited to the cleaning of coarse coal (particles with diameter greater than 1.0 mm. Fine coal was generally discarded (Mohns, 1997). In 1950 M.King Hubbert calculated feature oil production rate. We all known as ‘Hubbert peak[1]’. Same as this calculation in recent years has been a significant decreases in coal reserves. Especially higher grade coal deposits. The fine coal recovery has resulted recovery of tailings from traditional coarse coal cleaning process. Because of fine coal content in mineable coal is 35%, and for some reaches 60%.

Modern coal mining techniques generate large amount of fine particles that have to be recovered in coal washing plants. Fine coal processing has always been a problematic and costlier than the cleaning of a coarse coal (N.Vasumathi, T.V.Vijaya Kumar, S.Subba Rao, S.Prabhakar, G.Bhaskar Raju, S.Shiva Kumar, and Uma Raman, 2013). Froth flotation technique is effective and best available technique for enriching fine coal. Flotation is a solid-solid separation process in aqueous solution established on the difference of hydrophobic characters of the substances to be separated.

Ukhaa Khudag is 2700 t/h Coal handling and preparation facility utilizing 2 stage DMC + Spiral + Flotation to process coal to produce a coking and thermal product. Plant originally processed coal from the Tavan Tolgoi seams 3 and 4, which displayed good results for the flotation process. The Ukhaa Khudag CHPP currently process coal from more than five different seams of TT deposit. These are including 0C and 0B seam which ash content varies from middle to high. The flotation tailings ash was in the region of 35-45% ad indicating that there was still coal available to be recovered particularly since Ukhaa Khudag produced both a coking and a thermal coal product. In order to evaluate whether the flotation yield could be increased to recover additional coal, a laboratory scale flotation test work was conducted at GMIT processing laboratory.

This research work devoted to a small area of flotation, which is the laboratory scale batch froth flotation testing in different chemicals and compare laboratory experiment into industrial froth flotation. In order to obtain an applicable flotation model, two major fields are selected in this research work.

1. In order to overcome the chemical effects in froth flotation. Whatever using different chemicals and study moisture, ash, sulfur content and coking property of the flotation

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[1] **The Hubbert peak**, n. Theory says that for any given geographical area, from an individual oil-producing region to the planet as a whole, the rate of petroleum production tends to follow a bell-shaped curve. It is one of the primary theories on peak oil.

product.

2. In Heuristic rule for separation operation number four is: ‘Prefer separation operations with proven technological experience’ (J.Hampe, 2018). Therefore trying to find factor which connect laboratory flotation with industrial flotation. Then this work will helpful to bring close laboratory scale into industrial scale of flotation.

The operating factors include the flotation solids concentration, the air flow rate, impeller speed, the feed size, and the froth stability. The froth stability is closely related to the frothier type and dosage. This research work is carried out to determine effects of the different chemical and find out factor of connection between laboratory experiment and industrial experiment.

## 1.2. Objective of the work

The main objective of this study was to investigate the effects of different chemicals on the flotation performance for a high ash coal seam of TT deposit and comparison of laboratory experiment and industrial flotation experiment. Two different coals (layer of OC upper and OC upper mid) were used into laboratory flotation. Froth flotation tests were operated using a Laboratory Flotation Machine of 3 liter capacity. Chemicals used MIBC[2] (methyl-iso-butyl-carbinol) as frothier, diesel as collector, and SNF Flomin F-810, F-430, and F-422 as comparing frothier. Coal properties were characterized by moisture, ash, and sulfur content and free swelling index.

Preliminary test work is done with in Ukhaa Khudag coal laboratory, which is Drop shutter test, and size analysis. Drop shutter test is representing coal crushability for transportation of extraction into the feed stock. Coal samples size were less than 5.0mm. Then wet screen test has proceeded for different size fractions: above 500 microns, 250 to 500 microns, 125 to 250 microns, 63 to 125 microns, 32 to 63 microns, 20 to 32 microns, and below 20 microns. After wet sieve, plotted size distribution curve of using Rosin-Rammler distribution method.

In laboratory flotation test used same as coal preparation plant’s size of below 0.25 mm. The concentration of the chemical is defined study of coal preparation plant dosage and reference from flotation study papers. Other conditions such as wetting time, pH value, impeller speed, air flow rate, and skimmer rotation collection increments are determined by standard test method for laboratory froth flotation of coal in a mechanical cell (Material, 2004) and also industrial way.

The 200 grams coal (dry basis) in 3-liter cell were used for the final stage of froth flotation test, and performing flotation tests to compare different chemicals which is frothier of MIBC, and SNF Flomin F-810, F430, and F-422. Ash, moisture, and volatile matter were determined for flotation concentrations (top product) and rejects (bottom products).

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[2] **MIBC**, n. methyl-iso-butyl-carbinol (4 methyl 2 pentanol)

# 2. BACKROUND

## 2.1. General information about the coal

The name *coal* is thought to be derived from the Old English *col*, which was a type of charcoal used at the time. Coals is also referred to in some areas, as *sea coal* because it is occasionally found washed up on beaches, especially in northeastern England. Generally, coal was not mined to any large extent during the early middle Ages (prior to A.D. 1000) but there are written records of coal being mined after that date. However, the use of coal expanded rapidly, throughout the nineteenth and early twentieth centuries. Thus increased popularity has made it necessary to device acceptable methods for coal analysis, with the goal of correlating fuel composition and properties with behavior (Speight, 2005).

During the Carboniferous, there were several periods when forests died and/or were flooded. The dead plants were decomposed into pet and covered by sediments and water. This cycle repeated several times. In deep layer, pressure compacts the peat[3], thereby reducing the water content and increasing the carbon content. Finally, several times repeated peat were formed into coal. Coal has been used as a fire sources since 1800 years. Out of more than 7000 million ton of coal extracted every year, about half is mined by the biggest producer, China. (Karthe, 2017).

After petroleum, coal is the second largest source of energy in the world, accounting for around 25% of the total world energy consumption. We know coal is chemical form from carbon. But carbon is not common.

In fact:

- Carbon comprises only 0.04% of the mass of the earth.
- Carbon comprises only 0.01% of the mass of the crust of the earth.
- Only 1 in 5000 atoms of carbon occurs in a form capable of reacting with oxygen (‘dynamic’ carbon)

Let consider about coal definition:

Coal is a combustible, organic, sedimentary rock derived from vegetable matter that accumulated under conditions which prevented complete decay and became modified chemically and physically by natural agencies (Sanders_G.J., Frank_Pollard, Tony_Partridge, Stuart_Nicol, 2007).

Coal is an organic sedimentary rock that contains varying amounts of carbon, hydrogen, nitrogen, oxygen, and sulfur as well as trace amounts of other elements, including mineral matter (Speight, 2005).

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[3] Peat, n. ‘vegetable matter decomposed by water and partly carbonized for use as fuel’. It is the most primitive stage of coalification.

In *Figure-1* shows an analysis of world coal reserves according to coal type and potential use (Sanders_G.J., Frank_Pollard, Tony_Partridge, Stuart_Nicol, 2007).

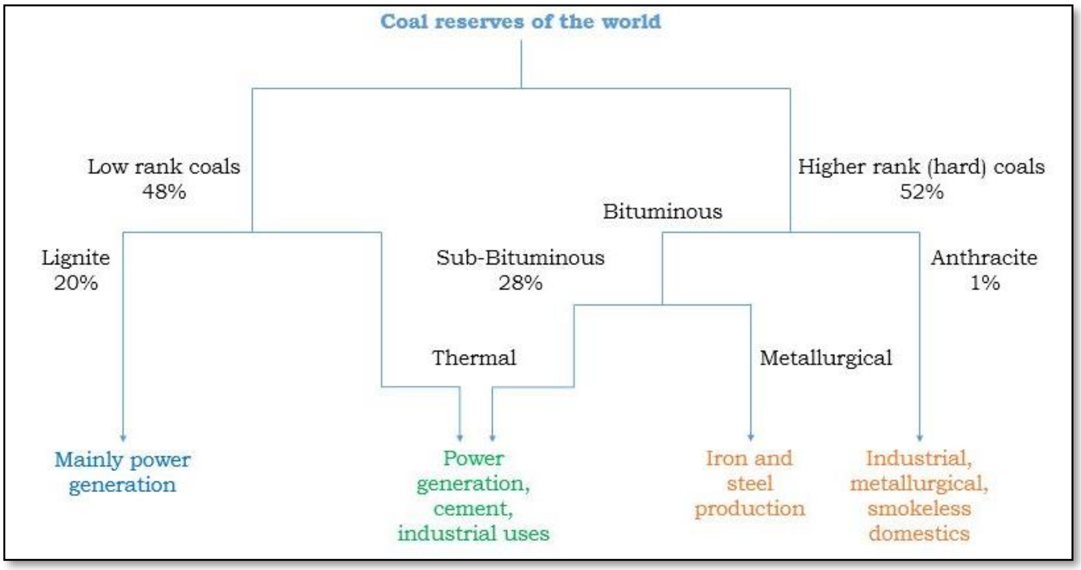

*Figure 2.1-1 World Coal Reserves according to Type and Use (Source: World Coal Institute)*

As far as coal use is concerned only the organic combastible parts of coal, which easily release heat (energy) on burning. Coal is formed from plants and parts of plants such as woody material, bark, leaves and spores. Although these plants are commonly referred to as trees they were, stictly speaking, giant fern-like plants differing from most of the tress familiar to us today.

Many countries with a sizeable coal industry have developed their own classification of coals, essentially focusing on the types in their respective deposits. As a result, there are many different and sometimes confusing categories of coal, depending which classification one reads. The Australian Standard for the coal classification (*AS 2096 – Classification and Coding System for Australian Coals*) divides coal into higher and lower rank based on calorific value limit of 27.00 MJ/kg dry and ash-free basis (Table 2.1-1). For historical reasons the American ASTM[4] classification has been well understood by customers of Australian exporters. As Australian producers deal with many customers internationally the use of International or ASTM classification is recommended, as preferred by customers.

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[4] **ASTM** n, American Society for Testing and Materials

*Table 2.1-1 Summary of ASTM Classification with Corresponding Reflectance Value*

| Class/Group | Volatile matter % (daf[5]) | Calorific value MJ/kg (dmmf[6]) | Reflectance % | Agglomerating |
|---|---|---|---|---|
| **Anthracite** | 2 – 8 | - | >2.5 | No |
| **Semi-Anthracite** | 8 – 14 | - | 2.0 – 2.5 | No |
| **Low volatile bituminous** | 14 – 24 | - | 1.5 – 2.0 | No |
| **Medium volatile bituminous** | 22 – 31 | - | 1.5 – 1.1 | Commonly |
| **High volatile bituminous A** | 31 – 49 | >32.5 | 1.1 – 0.75 | Commonly |
| **High volatile bituminous B** | 29 – 50 | 32.6 – 30.3 | 0.75 – 0.65 | Commonly |
| **High volatile bituminous C** | 29 – 50 | 30.3 – 25.5 | 0.65 – 0.5 | Yes |
| **Sub-bituminous** | 40 – 50 | 25.5 – 19.3 | 0.5 – 0.4 | No |
| **Lignite** | 44 - 69 | <19.3 | <0.4 | No |

## 2.2. Coal Type

### Macerals

When observed under a microscope, the carbonaceous matter of coal is not homogeneous but is seen to consist of various parts termed macerals. In contrast to minerals, maceral classification is less rigorous. Macerals do not have a well ordered crystallographic structure and an individual maceral may also exhibit variation in its technological properties. The macerals in bituminous coals have been divided into three major groups on the basis of their relative reflectance: vitrinite, liptinite, and inertinite.

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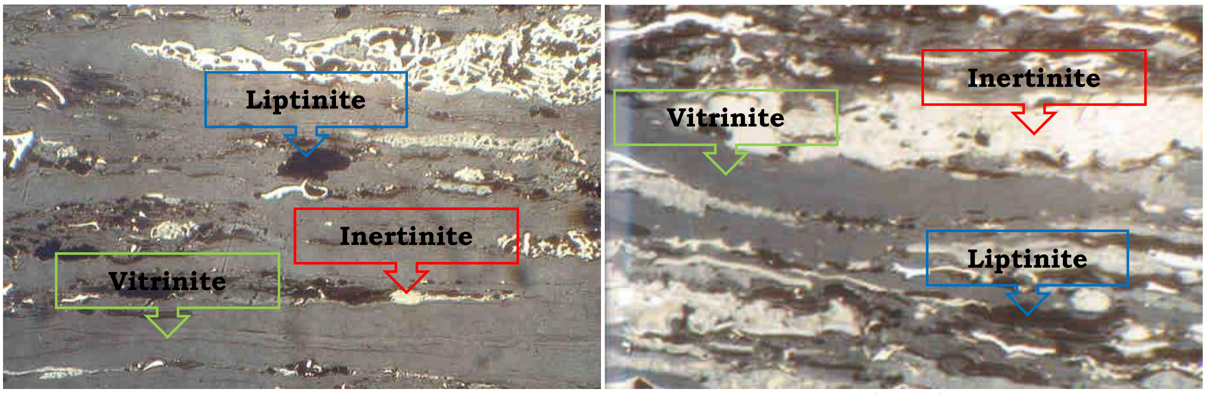
[5] **Daf** n, Dry and Ash-Free

[6] Dmmf n, Dry, Mineral-Matter Free



*Picture 2.2-1 Photomicrographs of two high-volatile bituminous coals. The horizontal field of view is approximately 200μm (0.2mm). The maceral groups are labelled. (Services, 2017)*

## Vitrinite group

Vitrinite is derived from the cellulose of plants. Prior to burial this component was not oxidised and during coalification it was gelified by humic acids and desiccated to produce the mid-grey ground mass of the coal. In coal seams or hand specimens the vitrinite macerals are concentrated in the brighter bands of the coal. At this level of observation it often exhibits conchoidoal fracture.

Vitrinite usually occurs in concnetrations between 30-85% in most bituminous coals. However, there are coals from New Zealand and Indonesia that contain up to 95% vitrinite. As in mined coal substances about 40% to over 90%. Because of the relative friability of this constituent it tends to accumulate in the finer size fractions. For given coal rank, vitrinite's chemical composition is slightly enhanced in hydrogen and lacking in oxygen compared to inertinite. Vitrinite is generally fusible in the coking process. The vitrinite group of macerals is further subdivided into teleovitrinite, detrovitirnite and gelovitrinite on the basis of morphology and association with surrounding macerals.

## Inertinite group

Internitite is drived from the cellulose of plants, the same precursor[7] material as that for vitrinite. However, this material is subjected to a different coalification pathway. This component was oxidised[8] prior to or during burial. This may occurs in a number of ways including bia swamp fires, lowering of the water table, local highs in the swamp, vegetation caught up above the water table etc. Exotic methods for oxidation that have been proposed include dreeze drying and fungal attack. Inertinite is  brighter than vitrinite when observed under a microscope, however, in a coal seam or hand specimen it is the dominant constituent of the duller bands within the coal. Inertinite usually occurs in concentrations between 15% – 70%. Inertinite is more likely to be infusible in the coking process. However, some Inertinite is fusible. The inertinite group of macerals is further subdivided into semifusinite, macrinite, micrinite, funginite, fusinite and inertodetrinite on the basis of relative reflectance and morphology.

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[7] **Precursor,** n. Something that happened or existed before another thing, especially if it either developed into it or had an influence on it (University, 2018)

[8] **Oxidised**, v. The component takes up oxygen resulting in the formation of some oxygen compounds.

**Liptinite group**

The macerals of the liptinite group are drived from the resinous and waxy material of plants, including resins, cuticles, pspores, pollen and algal remains, generally material high in hydrogen. Liptinite has high volitile matter content. Liptinite plays a much lesser part in coke quality than vitrinite and actually most of the liptinite present is drive off with by-products during coke manufacture.

Typically Liptinite occurs in concentrations of less than 15% in most humic[9] coals and usually in concentrations of less than 5%. Nevertheless, there are coals that form in unique environments that can produce very high concnetrations of liptinites. These are called sapropelic[10] coals. Typically thay composed almost entirely of spore precursor material, in which case they are termed cannel coals, or algey precursor material, in which case they are termed boghead coals.Because of the relatively high hydrogen content and more aliphatic organic compounds in the liptinite macerials, these coals have been exploited as a feed stock for petroleum generation. With in the mid-volatile rank range, the reflectance of liptinite approaches that of vitrinite and it is no longer different under the microscope.

## 2.3. Coal Preparation Plant

It is known Mongolia has one of the world’s largest coal deposits, and the future development of that attracts from many countries of the world. (Nagata Engineering Co., 2017)

Mongolian Mining Corporation (‘MMC’ or the ‘Company’; SEHK Stock Code: 975) is high-quality coking coal producer and exporter in Mongolia. The company owns and operates two open-pit coking coal mines – Ukhaa Khudag (697.8 million tons) and Baruun Naran (240.0 million tons), both located in South Gobi province of Mongolia. MMC’s operations have grown rapidly from a green-field project from 2009, to a World-standard mining complex to date. With its premium quality coal products, international standard project development and effective management practices, The Company has already secured its position as the largest producer and exporter of washed coal in Mongolia. (Mongolian Mining Corparation Co., 2013)

CPP has a following main objects. Which is administration; maintenance store, maintenance shop, dewatering plant, motor control room, steam oven, and raw coal & product rejection object etc. In CPP’s feasibility study’s planned, plant output is 900 tons per hour. But it is depending on operation process. Because of maintenance and fail of crusher, belt, pipe, conveyor and equipment. Plant has a continuously going process. That is why if any section has a failure, then plant will stop fully. For

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[9] **Humic Coal**, n. Coal that exhibit alternating bands of dull and bright material. These bands are usually not more than a few centimeters in thickness. These coals derived from a range of organic precursor materials. These coals are by far the most common type of coals.

[10] **Sapropelic Coal**, n. Coals that exhibit a massive structure, often with conchoidal fracture. They may feel greasy to touch. These coals are usually highly concentrated in a single precursor material, usually spores or algae.

example, if plant's air pressure less than 540Kpa, then plant will stop automatically.

Coal Preparation Plant's process has a three main section. Which is coarse, fine, and ultrafine. It is depending on material's feed size. Coarse circuit size range is below 50mm to above 1.25mm, in fine below 1.25mm to above 0.25mm, finally ultrafine circuit feed size is below 0.25mm. In the coarse section's using equipment is feeder, screen, cyclone, feed sump and centrifuge. Fine section's using equipment is cyclone, sieve bends, spirals, feed sum, and centrifuge. Ultrafine section's using equipment is feed sump, flotation cell and centrifuge. Also all section has an ancillary equipment. In Annex-1 showed CPP's flow sheet.

### *Coarse circuit (-50mm to +1.25mm):*

Energy Resources LLC is planned 70% of feed will enriching in coarse section in the Feasibility Study. This sections size distribution is -50mm to +1.25mm. And using main equipment is feeder, screen, cyclone, centrifuge, and magnetic separation. Main separating/enriching equipment is cyclone. Coarse section will produce coking coal, thermal coal, and rejection. This section's main role to compose mass of production.

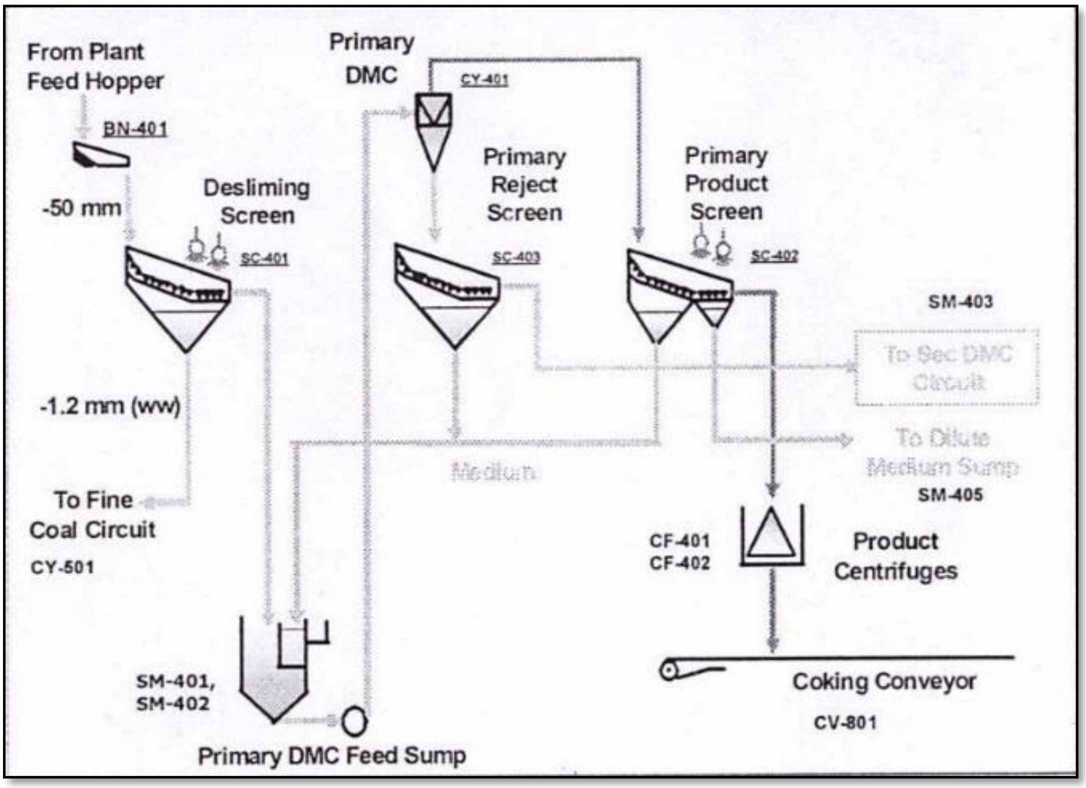


*Figure 2.3-1 Primary DMC circuit simplified flowsheet*

*Figure 2.3-1 and 2.3-2 showed* coarse section's simplified flowsheet.

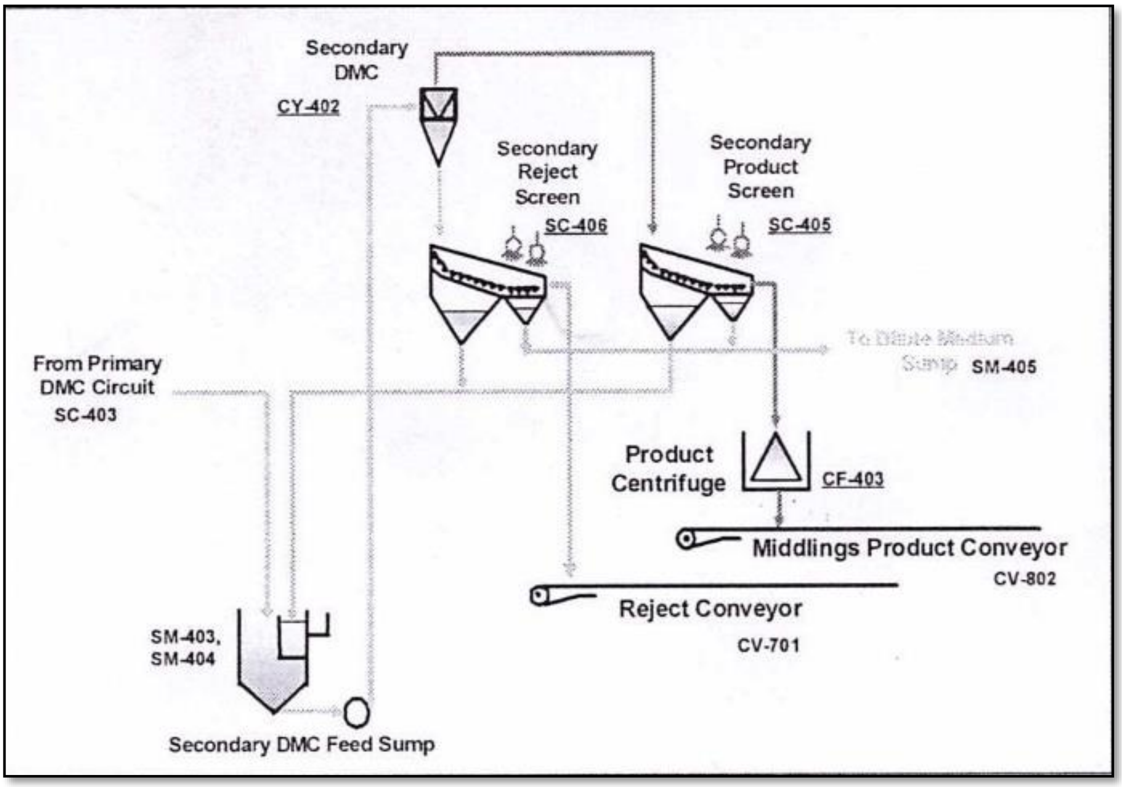


Figure 2.3-2 Secondary DMC circuit simplified flowsheet

*Fine circuit (-1.25mm to +0.25mm):*

10-20% of feed will separated fine section. Size distribution is -1.25mm to +0.25mm. This

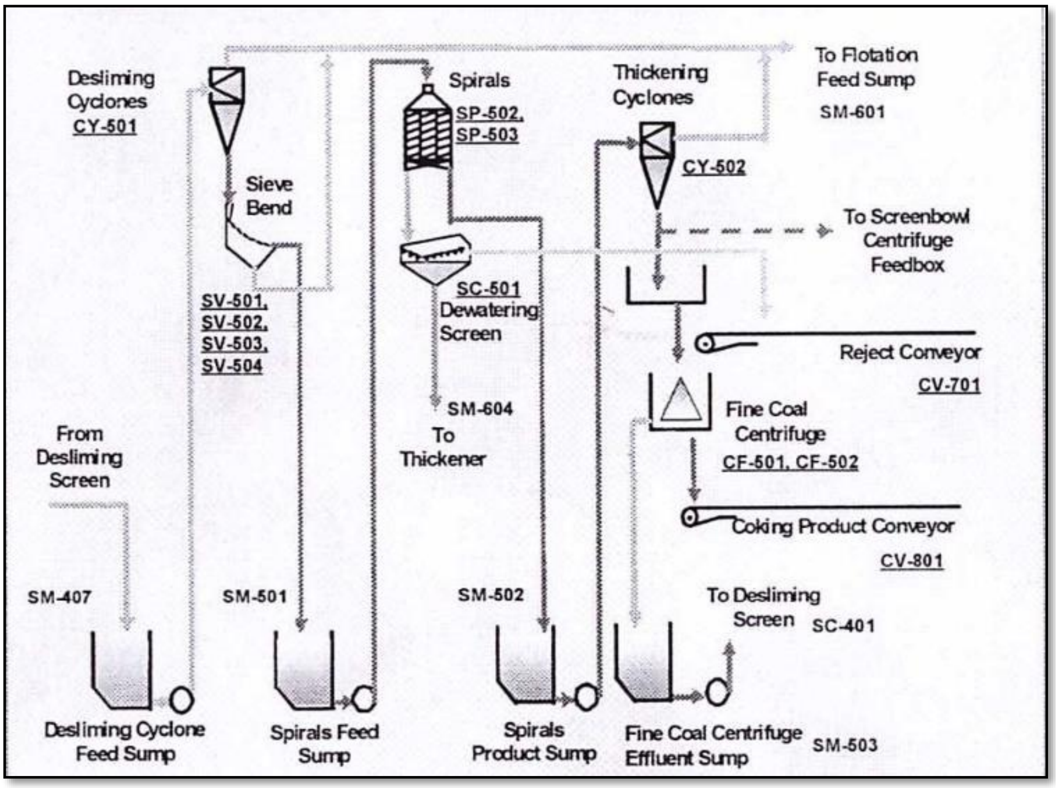


Figure 2.3-3 Spiral circuit simplified flowsheet

section will produce only in coking coal. Fine particles equipment is cyclone, sieve bends, spirals, screen, and centrifuge. Main product of coking coal, thermal coal, and rejections are produced. Main role of this section is to reduce ash and moisture and other no useful content of the product.

Figure 2.3-3 shows the fine section's flowsheet and function of how sieve bend, spiral and cyclone are connecting each other, and supplying and production lines.

*Medium and magnetic separation:*

Magnetite is CPP's main usage of control medium circuit. Using magnetite has a for certain reason. Main reason is a magnetite separation is very easy and cheaper. Which is using only on magnetic separation. Magnetic separation part is producing two output, one is a going to do? sliming screen, and another one is going to magnetite addition splitter box. Magnetic addition splitter box is adding magnetite to correct medium sump for after scanning medium dense. If DMC feed sumps dense is less than optimum value, then adding magnetite from splitter box (figure 2.3-4).

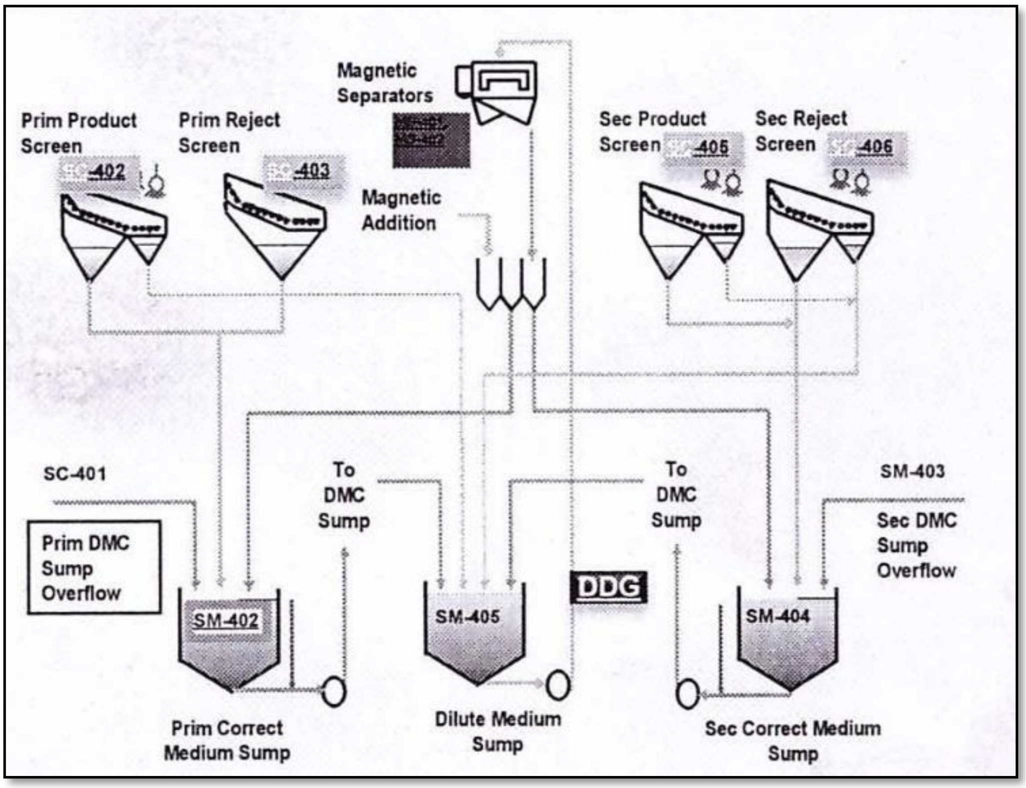


*Figure 2.3-4 Medium and magnetite recovery circuit*

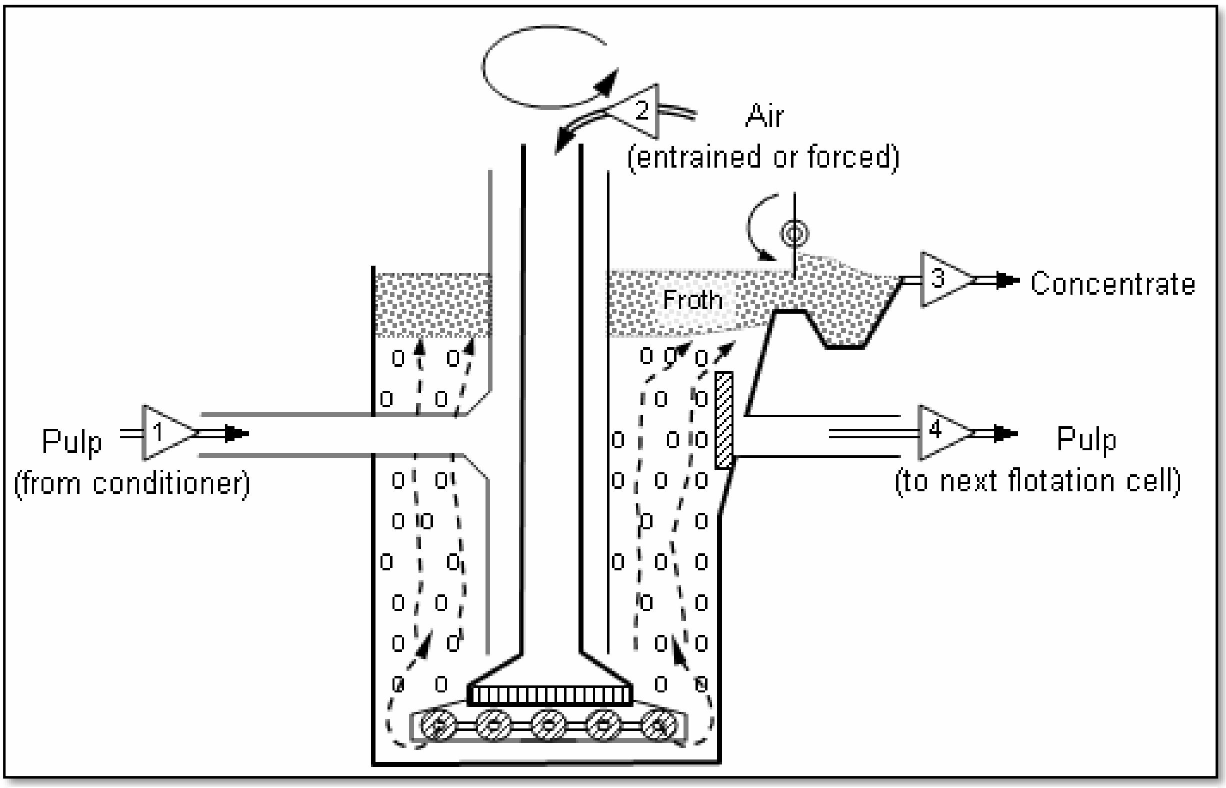
*Ultrafine circuit:*

In ultrafine section producing 20-10% of all production in plant. This section is producing high quality production. Main role is reducing ash content. Equipment is flotation cell, and centrifuge. Key enriching equipment is flotation cell. Products quality depending on ultrafine section's production. This section producing only on coking coal and rejection. Rejection going to tailing. Which is recovering water, then used to plant's water supply.

## 2.4. Introduction to Flotation

Froth flotation is a widely used techniques in the mineral process of concentrating a valuable material from an ore (E.Woodburn, 2000). Concentration by froth flotation has been well established process for recovery of metallic ores since it is discovered in Broken Hill in 1905, and it was adapted into coal preparation where it has proved successful for the difficult task of adequately cleaning coal fines (Sanders, 2007). The original patents for the flotation process were secured by C.V. Potter in 1901 and by G. D (Center, 2007).

Froth flotation is a process for separating hydrophobic[11] /water hating/ materials from hydrophilic[12] /water loving/. A few mineral, like sulfur, are naturally hydrophobic, so they can be floated directly, but most minerals are hydrophilic and have to be made hydrophobic by adding selected surface-active chemicals called collectors (Maurice C.Fuerstenau and Kenneth N.Han, 2003). These chemicals coat or absorb on the wanted minerals, usually assisted by any of a number of secondary or auxiliary chemicals. Most of secondary or auxiliary chemicals contribute flotation by absorbing selectively on the particle or by complexing with the chemical species that touch with adsorption of collector on ores.



*Picture 2.4-1 Principle of froth flotation*

*Picture 2.4.1* shows the mechanism of the flotation in a mechanical flotation cell. Air feeding bottom section is agitator /bottom of the flotation cell/which provides enough turbulence in the pulp

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[11] **Hydrophobic**, n. is the physical property of a molecule that is seemingly repelled from a mass of water

[12] **Hydrophile**, n. is a molecule or other molecular entity that is attracted to water molecules and tends to be dissolved by water.

phase to promote collision of particles and bubbles which result in the attachment of particles to bubbles and their transport into froth phase for concentrate. Froth flotation can only be applied to relatively fine particle due to there are large adhesion between the particle and bubble been less than the particle and the bubble will therefore drop it is load.

The activity of a mineral surface in relation to flotation chemicals in water depends on the forces which operate on that surface. The forces tending to separate a particle and a bubble are shown in *Picture 2.4.2*. Tensile forces lead to development of an angle between the mineral surface and the bubble surface. The three phase equilibrium between the air bubble, mineral surface, and water can be described by the respective interfacial tensions according to Young's equation (L.Weiss, 1985):

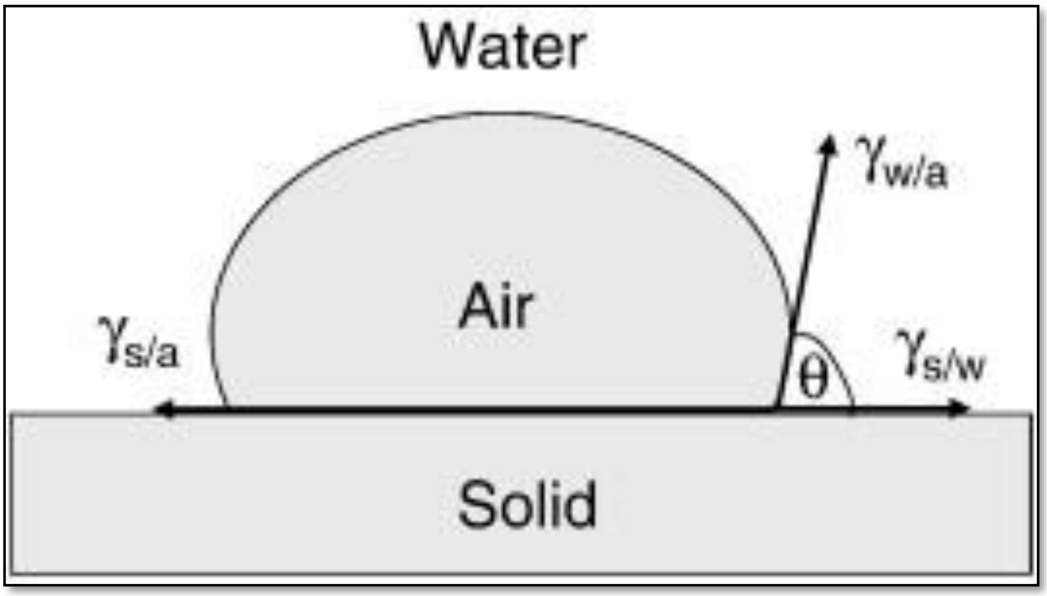
$$\gamma_{s/a} = \gamma_{s/w} + \gamma_{w/a} * cos\theta$$

Where $\gamma_{s/a}$, $\gamma_{s/w}$ and $\gamma_{w/a}$ are the surface energies between solid and air, solid and water, and water and air respectively, and θ is a contact angle between mineral surface and the bubble. When air bubble does not displace the aqueous phase, the contact angle is zero. On the other hand, complete displacement to the water represents a contact angle of $180^0$. Values of contact angle between these two limits provide a hint of the degree of surface hydration or conversely, the hydrophobic character of the surface.

The force required to the particle-bubble interface is called the work of adhesion, $W_A$, and is equal to the work of required to separate the solid air interface and produce separate air-water and solid-water interface, i.e (B.A.Wills, T.J.Napier-Munn, 2006).

$$W_A = \gamma_{w/a} + \gamma_{s/w} - \gamma_{s/a}$$

Combining with in Young's equation:



*Picture 2.4-2 Contac tangle between bubble and particle in an aqueous medium*

$$W_A = \gamma_{w/a} * (1 - \cos\theta)$$

Bubble attachment process can be described work of adhesion and work of cohesion or water. For attachment to be effected, the work of adhesion of water, must be less than the work of cohesion of water.

$$W_A < W_C$$

The work of adhesion is defined as the work required remove liquid from the solid surface leaving an adsorbed water later in equilibrium with a saturated gas phase. The work of adhesion consists of three component.

$W_I$ – Ionization energy, arising from coulombic attractive forces at the solid surface.

$W_H$ – Hydrogen bond energy, arising from coordination forces, the dipole[13] interaction of the solvent with the solid surface.

$W_D$ – Dispersion energy, arising from solvent interaction with induced dipoles at the solid surface.

$$W_A = W_I + W_H + W_D$$

As a part of these appearance which determine whether or not water is displaced from the surface by an air bubble, charge separation between solid and aqueous phases occurs, and the solid obtains a surface charge with respect to the aqueous phase.

## 2.5. Coal Flotation

Froth flotation is one method of cleaning coal that does not depend on density differences, and the force of gravity, to effect the separation (Sanders, 2007). Coal particles are lifted through the water suspension by the buoyant[14] action of air bubbles attached to them, with possibly a number of particles per bubble, and on arrival at the surface are skimmed off in the form of froth. The fine reject material does not attach to the air bubble, but remains in suspension in the bottom of vessel or flotation cell, and passes out of the system as tailings. It is important to realize that some reject may also attach to the froth concentrates due to entrainment.

Froth flotation is a most usable to feed of coal less than about 0.5mm particle top size, and is thus truly a fine coal cleaning process. In Energy Resources LLC enriching particle size of less than 0.25mm in froth flotation cell. Too much fine clay in the feed may be disadvantageous to flotation performance because:

- ✓ Under some conditions, it can absorb collector, and may attack to the coal particles of chemical.
- ✓ It can absorb to the coal surface, acting as a hydrophilic colloid. Therefore overcome any tendency for the coal particles to attach collectors and float.

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[13] **Dipole**, n. A molecule that has both positive and negative regions.

[14] **Buoyant**, n. buoyancy or up thrust, is an upward force exerted by a fluid that opposes the weight of an immersed object.

✓ It can become determined with the froth, because it is ultra-fine size, so affecting the properties of the clean coal and ash content.

### 2.5.1. Surface properties of Coal and Mineral Matter

Coal has surface properties which enable it to become selectively wetted by oil and oil-like substances (Sanders_G.J., Frank_Pollard, Tony_Partridge, Stuart_Nicol, 2007). Shale[15] does not following this effect, but can be selectively wetted by water. In Table 2.5.1-1 shown contact angle data of coal rank.

Low rank coal has a very low contact angle.

*Table 2.5.1-1 Contact angle varies with coal rank*

| Material | Contact angle |
|---|---|
| **Freshly mined bituminous coal** | $30^0$ - $80^0$ |
| **Oxidized coal** | 0 - $30^0$ |
| **Shales** | $0^0$ |

### 2.5.2. Chemicals

Chemical is main part of the froth flotation and it is sensitive to control. Some chemicals are enable to mix with water directly, because of rapidly generating froth. Chemical adding rates are depends from the situations, which are type of coal, and the amount of reject material. Froth flotation using two main chemicals, which is collector and frothier. Collector is added to focus attach of coal to the bubbles. The frothier is added to focus on addition generation of bubbles, and stable enough to be recovered from the flotation cells in the product. There are several types of chemicals used for coal handling and preparation plant. For example methyl-iso-butyl-carbinol (MIBC), triton x-100, Brij-35, sokem C series, flomin F series, sodium dodecyl sulfate (SDS), hexadecyl trimethyl ammonium bromide (HTAB) (Wencheng Xia, Jianguo Yang, 2013), and oil (diesel) etc. Currently, ER's coal handling and preparation plant using single chemical (Sokem C series), which has both frothiering and collecting activity.

Polanga and Mahua oil used as collector to none coking coal. A replacement for this diesel-frothier system has been attempted by utilizing vegetable oils & biodiesel. But, all these studies were confined to laboratory scale only (N.Vasumathi, T.V.Vijaya Kumar, S.Subba Rao, S.Prabhakar, G.Bhaskar Raju, S.Shiva Kumar, and Uma Raman, 2013).

In this study we have used diesel as a collector, and MIBC as a frothier, and SNF Flomin F-

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[15] **Shale**, n. is a fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite

810, F-430, and F-422. Diesel and MIBC are commonly used in coal flotation as collector and frothier. SNF FloMin is a subsidiary of the SNF groups and manufacturer and market chemical for the minerals processing industry. FloMin F products are enhancing frothier performance. Used for the flotation of base metal sulphides, precious metals (gold, and silver etc.), industrial minerals, coal and various other non-sulphides.

*Collector:* A few coals are naturally attach to an air bubble. In case of a coal particle attaches itself to the air bubbles needs to be enhanced. This is reached by the use of chemical chemicals. Which is increase the contact angle and therefore the particles readiness to attach to the air bubble. Chemicals used to promote particle adhesion are called collectors. Collector's effect is to increase contact angle between coal and air bubble. Lower contact angle the more and stronger collectors need to be added for flotation.

In recent years, some short-chain volatile fatty acids and commercial fatty acids are used in the froth flotation of coal fines as an alternative to the conventional collectors (Meryem Ozmak and Zeki Aktas, 2006). Currently most common collector is diesel oil, which is used with dosage of 0.1-0.2kg/t of solids (Sanders, 2007). It is depending on the site requirements.

*Frothier:* Another using chemical is called frothier. It aids the formation of air bubbles which then form a sufficiently stable froth. Stable froth should be formed in flotation cell to get highly effective separation during froth flotation (Meryem Ozmak and Zeki Aktas, 2006).

Frothier' are extremely surface active at the air and water interface. Frothier used to generate froth in flotation cell, and also stabilize the bubbles long enough to allow them to be remove from the cell. Cresylic acid and pine oil have in the past been used for this reason. But have a largely been replaced by polyhydric alcohols. A popular frothier in this later class is methyl-iso-butyl-carbinol (4 methyl 2 pentanol). MIBC dosages are typically 10ppm (particle per million).

### 2.5.3. Froth Flotation Plant Operation

There are many combination of the flotation circuits. Single-stage, two-stage with or without recirculation of secondary products and variations of chemical dosing points are the most common one. Traditionally froth flotation feed has been less than 0.5mm fines. Froth flotation circuit for plant of Ukhaa Khudag CHPP shown in Figure 2.5.3-1.

Whilst there are many plants treating feed of 0.5mm top size, current tendency is to limit flotation to the finest sizes, generally below 0.150mm for streaming coal or 0.350mm for coking coal and consider further desliming, depending on the coal and it is marketability.

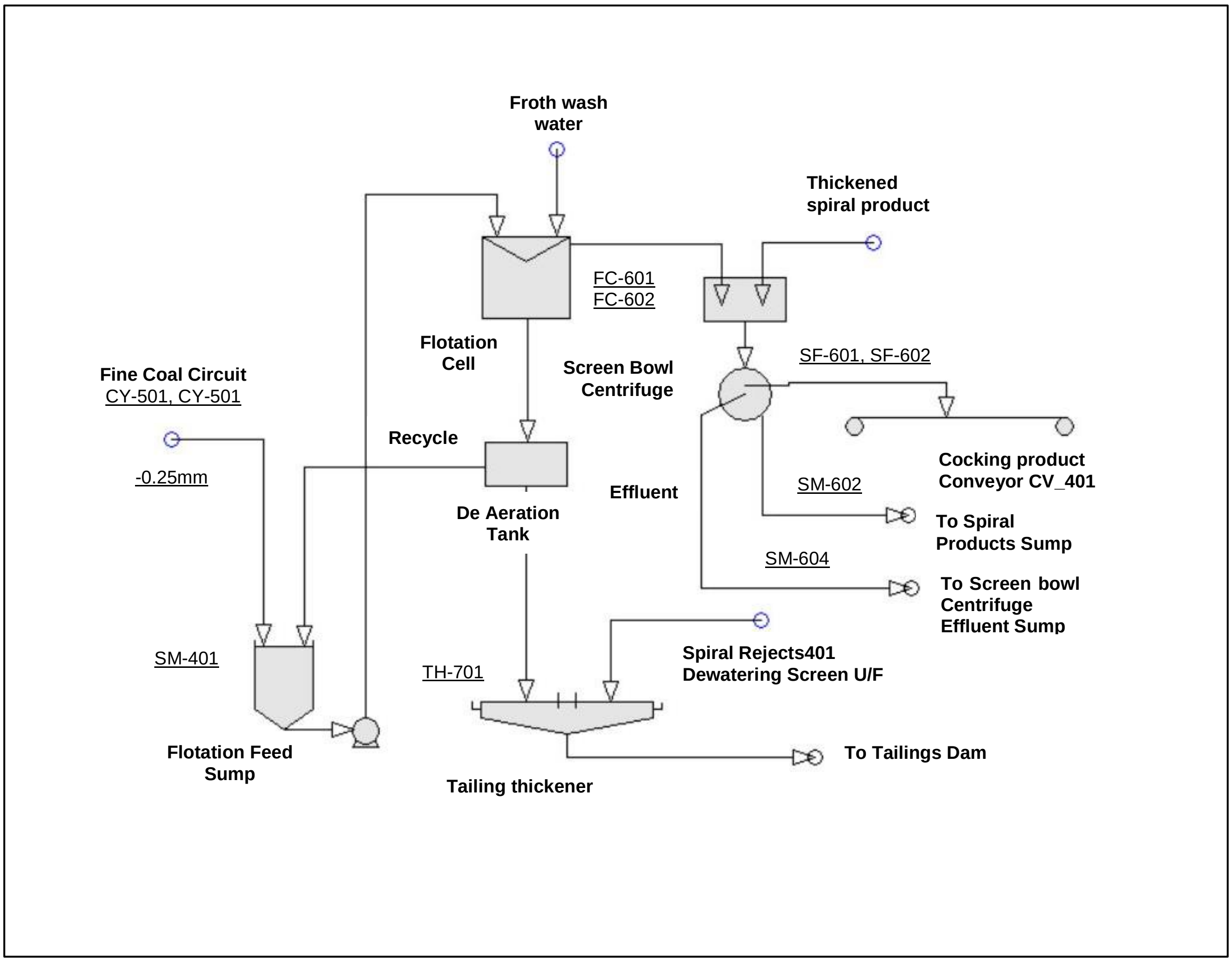


*Figure 2.5.3-1 Froth Flotation circuit in Plant of Mongolian Mining Corporation*

## 2.5.4. Flotation machines

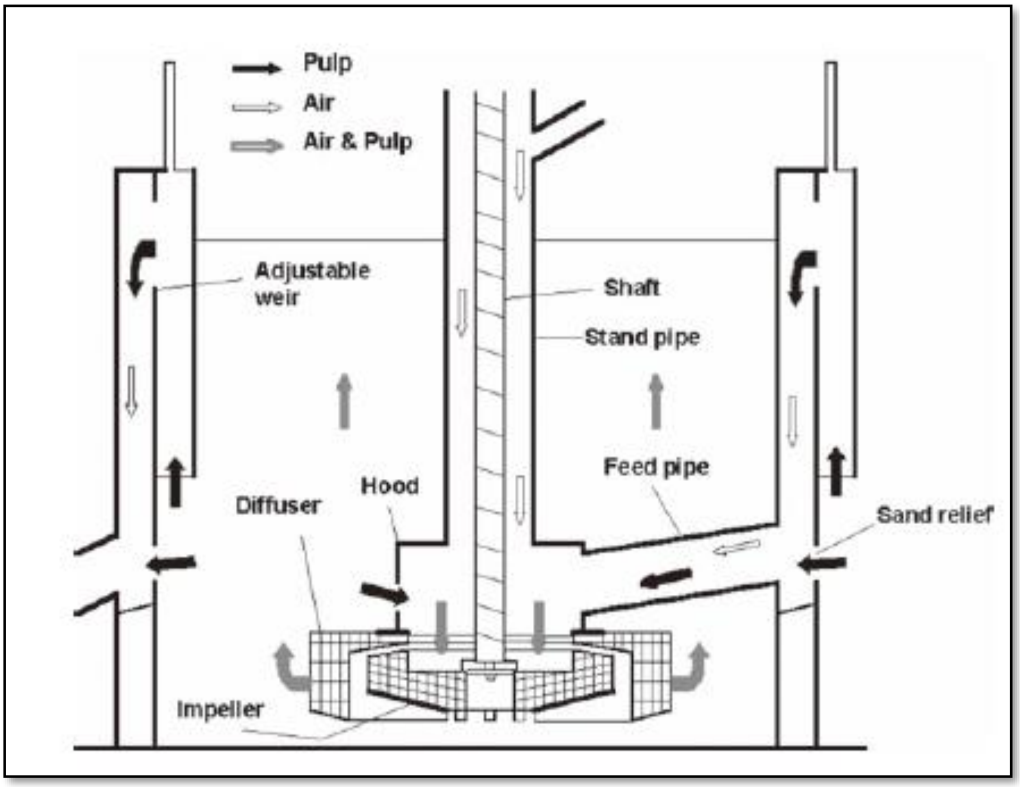
There are number of types of flotation machines. They are all produce air bubbles in the suspension in one way or another. All have arrangements to remove froth from the top of the vessel. There are three major types of cell in use industry:

✓ Mechanically agitated cells
✓ Column cells
✓ Jet flotation cells

Mechanical agitated cells are classic flotation cells of mineral dressing adapted to coal treatment (Sanders, 2007).

### Mechanical agitated cells

The best example is the sub-aeration cell. Which is air is introducing to the bottom of the cell from outside. The rapid rotation of the impeller draws air from outside the machine down the intake jacket surrounding the impeller shaft. The turbulent agitation mixes the air with the suspension, the object being to agree the coal particles to collide with an air bubble and become attached. Bubbles rise in the vessel, continuously attaching coal particles with them. Tailings pass on the next cell for further similar treatment and finally overflow out of the system. There are only one or two atmospheric air drawn flotation cells that have valves to control the amount of air to optimize flotation process.



*Picture 2.5.4-1 Mechanically agitated (sub aeration) cell*

**Column cells**

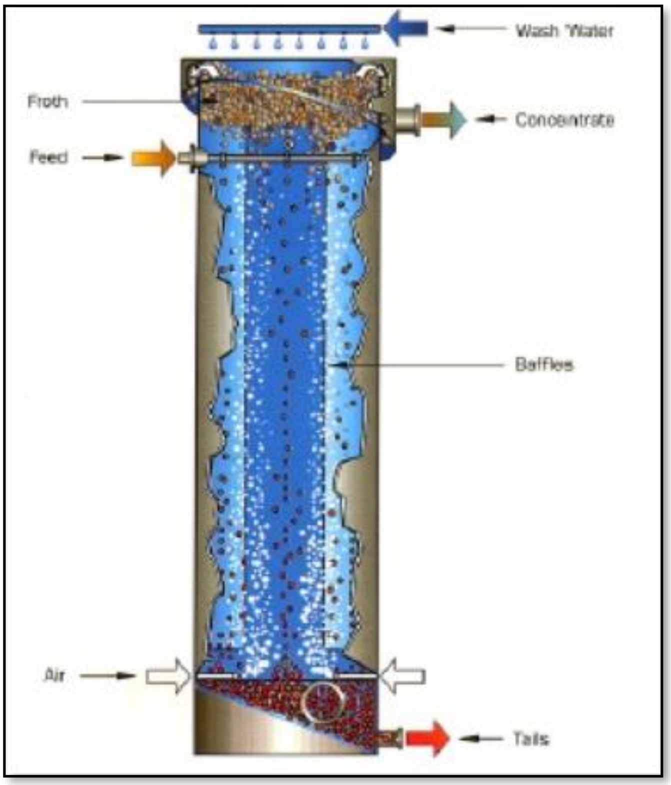
Two Canadians, P.Boutin and D.A.Wheeler are credited with the first application of column flotation for processing coal in 1967. Column flotation cell works on the same general procedure of particle and bubble attachment as conventional mechanical flotation. Most important difference is these devices can support a deep froth which facilities the efficient application of wash water. Which is ensures high-grade float product.

One of the most widely used column cell is the ‘CoalPro’ column cell. It is designed by Canadian Process Technology Inc and Eriez Manufacturing. The column height ranges from 7 to 16 meters high. Diameter up to 5 meters. High velocity of air injected into the bottom of column to create and disperse fine bubbles. Maximum superficial air velocity is 25mm/second. High aeration rate and larger bubble sizes (comparing into the Microcell system) is most suitable for processing de slimed flotation feed.

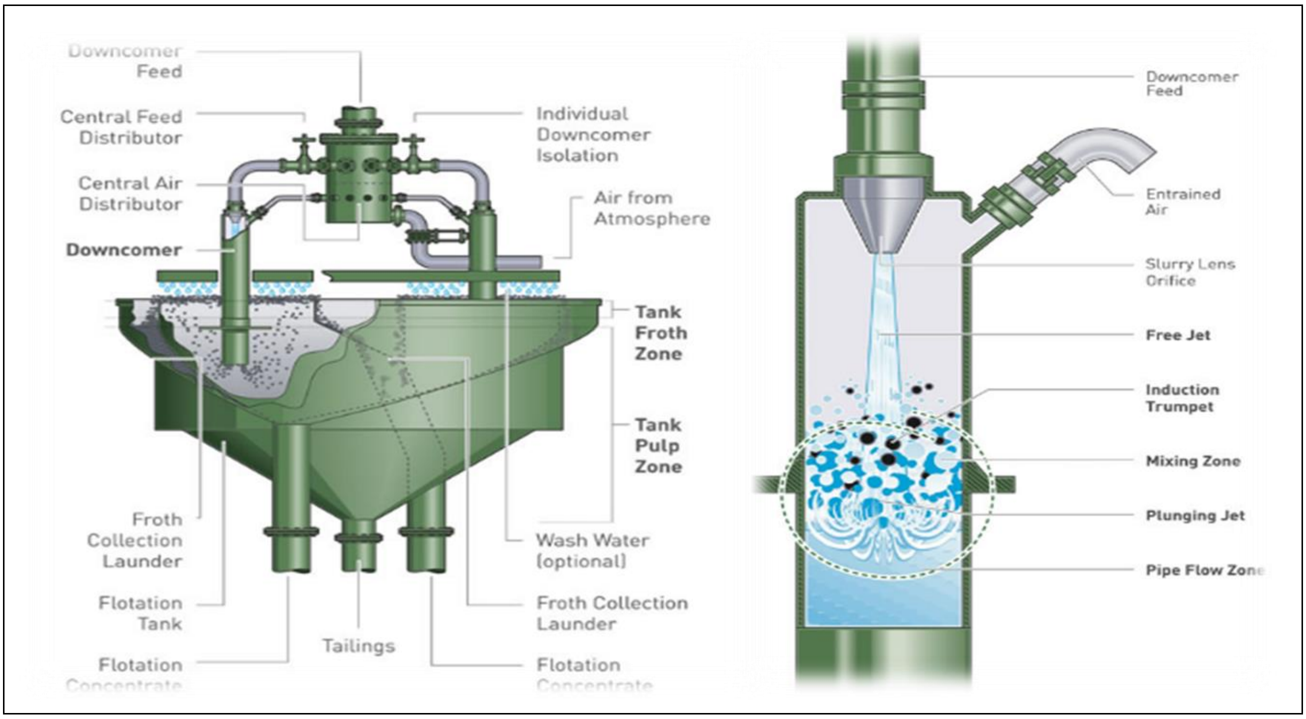
### Jet flotation cells

Most common type is the Jameson cell. It was developed initially for use in metalliferous processing plants. It has found ready acceptance in both the metalliferous and coal plants and there are many installations in coal mines and overseas. The Jameson cell basically contains three zones:

- ✓ An aeration or mixing zone. Which is bubbles are formed in a downcomer and contacted with particles.
- ✓ Recovery or pipe flow zone. Particles may attached into bubbles.
- ✓ Disengagement zone. Non recoverable particles release from the pulp as the bubbles rise into the froth concentrate above.



*Picture 2.5.4-2 'CoalPro' column cell*



*Picture 2.5.4-3 Jameson Cell*

Collector and frothier pumped into inlet orifice located at the head of the downcomer at approximately pressure of 150KPa. The operation of the orifice is to accelerate fluid and form a jet at approximately 16m/s. The jet plunges into the receiving fluid, entraining air in the process and evacuating air generates a vacuum in downcomer headspace. Process of evacuating air generates a vacuum in the downcomer headspace. The vacuum causes air to be sucked in via a control valve.

Behind reason is air flow goes from high pressure into low pressure. Which is downcomer head has a vacuum. Vacuum means lower than ambient pressure.

Bubbles size strongly determines the efficiency of froth flotation. If the larger bubbles are formed in the Jameson cell, then tendency to rise upwards the flow rate, because of their buoyancy. High flow rate causes the bubbles to be broken up forming new bubbles. The claimed advantages of the Jameson cell are own air flowing system, which is not using compressors. But it is not new method. It is reported that earlier machines using the plunging jet method of air entrainment were unable to control bubble size (Sanders, 2007).

# 3. EXPERIMENTAL PART

## 3.1. Material

### 3.1.1. Test plan

Figure 3.1.1-1 shows the main experimental scheme for this study. First, sample was split into two section. Sample one will drive vibrating wet sieve screen and analyzed by size analysis. Table 3.1.1-1 is shows sieve size for the wet sieve screen . The purpose of the size analysis is to determine size distribution of the coal sample.

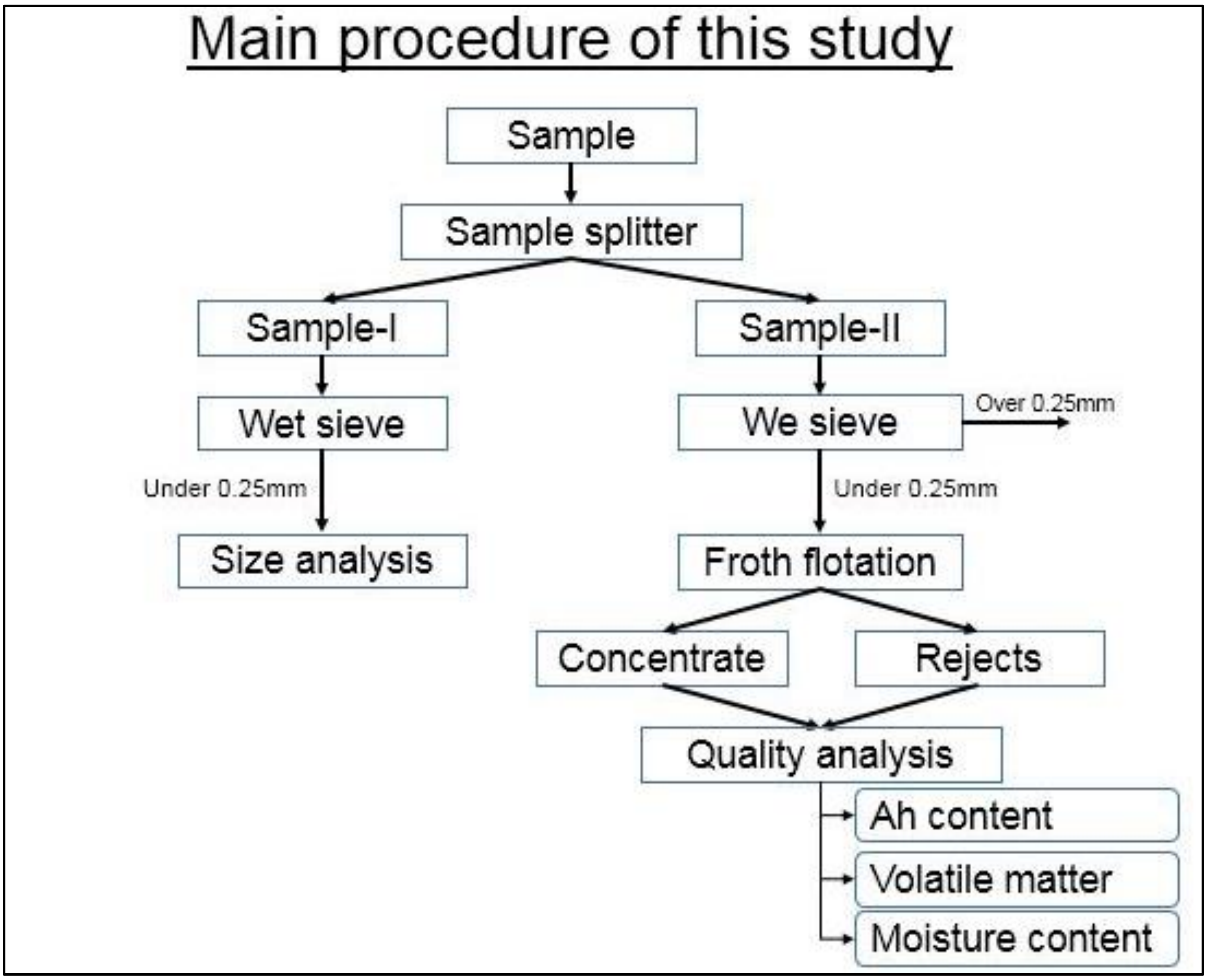


*Figure 3.1.1-1 Main procedure of the coal froth flotation study*

Sample #2 goes to the wet sieve. Flotation sample preparation sieve size is 0.25mm which is equal size compared to Coal Handling and preparation plant. Coal samples less than 0.25mm size were dried in laboratory r at $80^0$ C. After the drying process coal samples tested for laboratory froth flotation test. One flotation experiment is used 200 grams (dry basis) of coal sample. In flotation products separated concentration (top product), and reject (bottom product). Basically flotation method divided into two stages. Stage one is separation of floatable and non-floatable materials from the cell. Stage two is to collect concentrates (top products) in different times. The 6 concentration products, and one reject are produced during the Stage two on the other hand reject from the stage one is collected in one container. Finally, eight products will collect in one flotation experiment.

*Table 3.1.1-1 Tyler and US Standard (USS) Sieve Sizes*

| mm | Tyler | USS |
|---|---|---|
| **0.5** | 32M | No. 35 |
| **0.25** | 60M | No. 60 |
| **0.125** | 115M | No. 120 |
| **0.063** | 250M | No. 230 |
| **0.032** | 450M | No. 450 |
| **0.020** | 835M | No. 835 |

Quality analysis such as ash, volatile and moisture contents are determined for all products.

### 3.1.2. Sample description and preparation

Coal samples used in this study were taken from Tavan Tolgoi (TT) Coking Coal Deposit in Umnugobi aimag, Mongolia. The samples originated from two seams within the deposit:

1. OC seam; and
2. OB seam.

Ukhaa Khudag coal preparation plant (CPP) is one of the first modern wet coal processing plant in Mongolia which is managed and operated by Energy Resources LLC in Tavan Tolgoi coal basin. Ukhaa Khudag mine and CPP is started to operate from 2010, with an output of 15 million tonnes per year. In the CHPP, the feed splits into three process streams:

- Coarse coal (- 60 mm +1.2 mm ww ), comprising 65% of the plant feed, which is treated by six modules of 1300 mm heavy media cyclones
- Fine coal (-1.2 mm ww + 0.25 mm), which is treated by spiral classifier
- Ultrafine coal (- 0.25 mm), which is treated by flotation cell (Jameson)

The CPP produces a primary and secondary product via a two stage DMC process. The two stage DMC allows for coking and thermal products to be produced simultaneously. Figure 3.1.2-1 provides an overview of the process flowsheet.

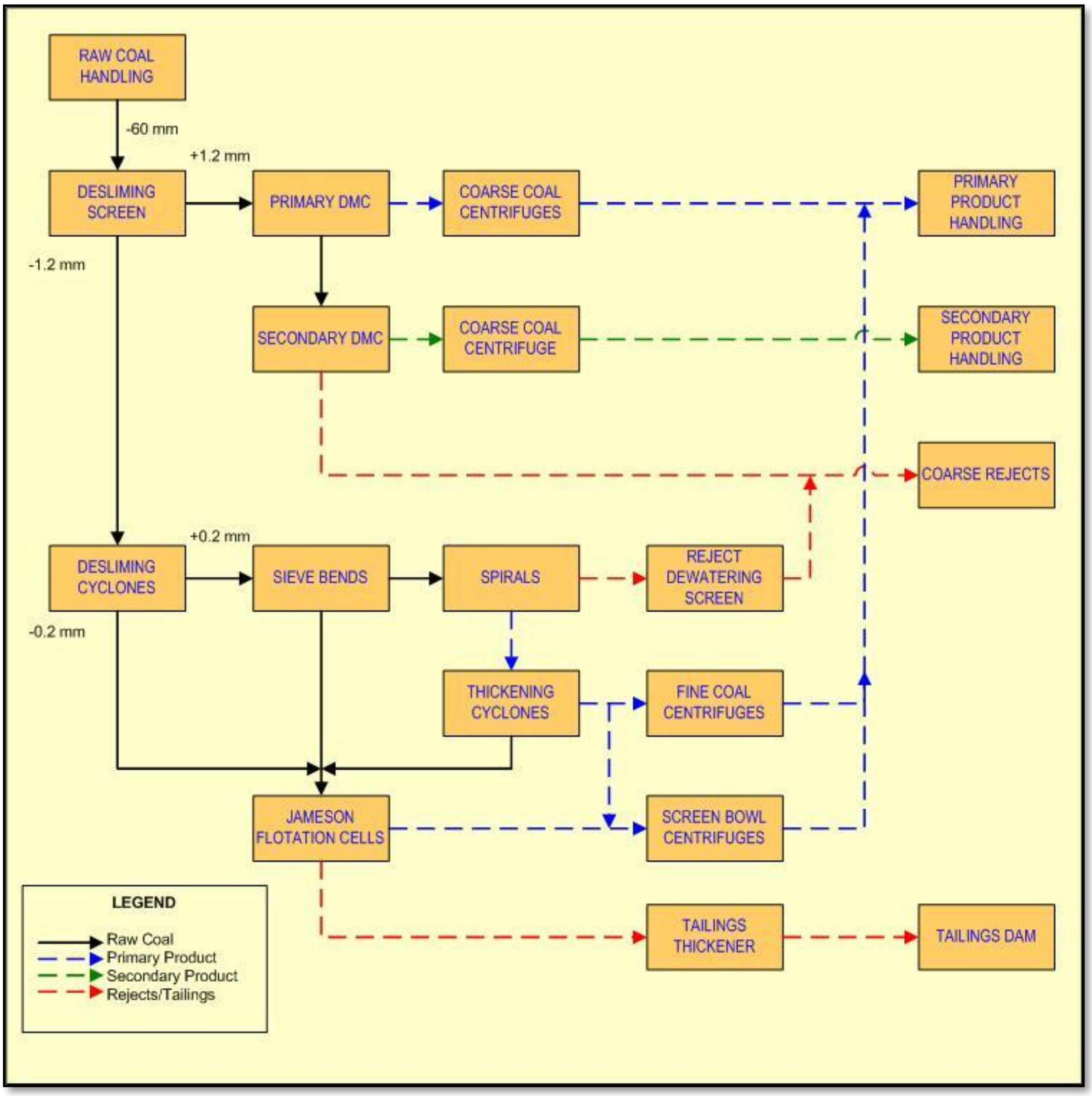
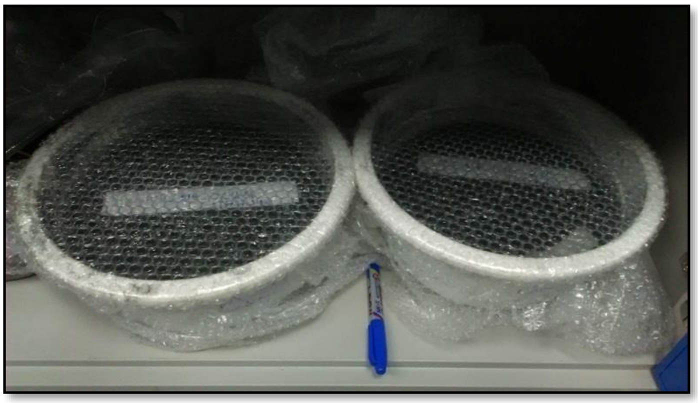


*Figure 3.1.2-1 Overview of process flow sheet*

To acquire the sample, at mine site, coal mine geologists obtained approximately 900 kg samples from each of the two coal seams. This composite sample was coned and quartered, and one quarter was retained. Further coning and quartering was conducted, and the remaining sample was drop shattered and wet tumbled in Ukhaa Khudag Coal Quality Laboratory. After initial preparation stage sample was screened at 0.5 mm using a dry sieve. The minus 0.5 mm material was sent to GMIT for flotation test work study. All flotation testing throughout this study was conducted on minus 0.25 mm material, as this is the maximum size of the coal processing plant flotation feed.

After received at GMIT processing laboratory coal sample was divided to collect a small representative sample from a cone quartered method and Riffle splitter (Picture 3.1.2-2) for the



Picture 3.1.2-1 Flotation experimental samples

Picture 3.1.2-2 Riffle splitter

purpose of particle size and quality analyses. Remained sample was dried in a low temperature oven to avoid surface oxidation and stored in sealed plastic bags until required.

### 3.1.3. Laboratory methods for determining coal characteristics

Chemical analysis is the process of defining a substance in terms of its fundamental components and measuring the proportions of components in coal sample.

**Chemical analysis:**

*Moisture:*

In moisture test has mainly five different types of moisture. *As received moisture* (ar), *air dry or air dried moisture* (ad), *total moisture* (TM), *equilibrium moisture holding capacity* (MHC), and *free moisture*. As received moisture is a moisture content of a sample at the time receiving. Air dry or air dried moisture is a moisture in the sample after it has attained equilibrium with the ambient where it is exposed. Which is after surface moisture is moved moisture value. Total moisture is defined as total moisture for commercial contacts, transportation and shipping determinations. Defining commercial way is to crush 4mm top size and then drive off the moisture in a drying oven at between $105^0$C to $110^0$C. Equilibrium moisture is the natural or bed moisture of coal in the ground (**AS 1038.17**). Free moisture is a more related into coal preparation. It is a value of difference between total moisture and residual moisture.

*Proximate analysis:*

Most common analysis performed on a coal is proximate analysis. Proximate analysis done on samples which have been equilibrated in the laboratory condition. In this study done for proximate analysis of *ash* content, and *volatile matter*. Ash is determined by burning the air used into furnace heated up $815^0$C with a slow current of air passing through the furnace chamber. Ash is formed from the minerals matter, and included with the coal. The goal for coal preparation is to produce clean coal, which is small amount of ash content.

Volatile matter is part of the coal. When coal rapidly heated up to 900$^0$C, then particles contact with hot air. High temperature in the furnace is used for decomposition of the complicated chemical mixtures of the coal. In the furnace heated up seven minutes. During this time volatile matter will leaving a coal sample.

*Ultimate analysis:*

Ultimate analysis is used for identify coal rank. This is the expressing structures of the coal matters and determining the main chemical elements in the coal. 99% of the organic portion of the coal is consists of the five main elements. Which is carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O).

Carbon (C) is the main component of the coal. When carbon content increases, coal rank will increase. Reaching up to over 90%, then it is high rank coal of anthracite. Carbon is the main energy source.

Hydrogen (H) is small quantities in the coal. It characterizes additional energy to carbon. It is also much higher heating value than carbon.

Nitrogen (N) is current in coal also small quantities in the coal. Usually less than 2-3%. Nitrogen is an environmentally important pollutant, because of after combustion it is generates nitrogen oxides ($NO_x$). $NO_x$ very harmful for the environment.

Sulfur (S) is unnecessary in every forum. During combustion sulfur converts into $SO_2$ and environmentally it is very harmful. For example, when it goes through the air, then reacts with water vapor. Then condensate phase of acid rain. Sulfur determination is a main interest in a coal preparation engineering. Sulfur is found in coal in main three forums. As iron connected pyrite, as inorganic sulfates connected with the mineral matter, and organic sulfur compounds in the coal (Battsengel Baatar, Munnkhshur Myekhlai, Yaruunaa Turmunkh, Chinbayar Majaa, Tseveendorj Gan-Erdene, Ulziikhuu Otgonbayar, Namsrai Javkhlantugs, 2017). Iron connected and inorganic sulfur can be removed easily form the coal. But organic sulfur compounds very difficult to remove.

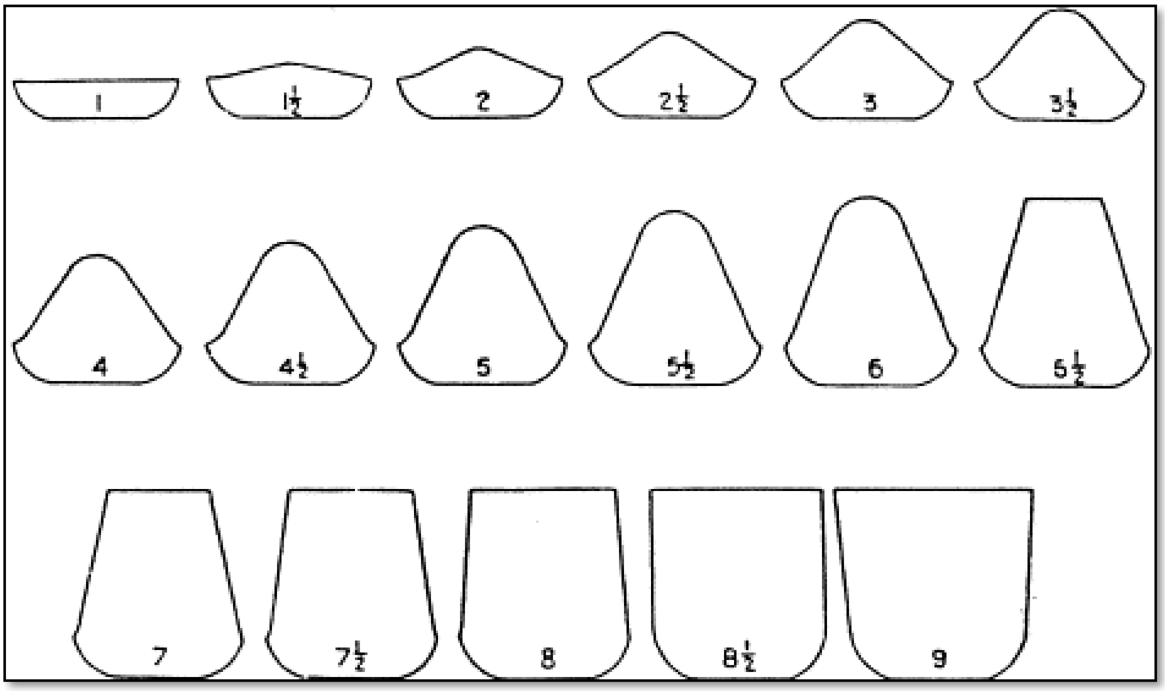
Oxygen (O) is commonly determined as differences by subtracting the sum of the other elements from 100%.

*Calorific value:*

Calorific value is the determining the heating value of the coal. This measures the amount of heat which is when coal is burned completely. It is measured by calorimeter equipment. Calorific value is determined by Mega Joules per kilogram (MJ/kg) or kilo calories per kilogram (kcal/kg).

*Crucible Swelling Number (CSN):*

While heated strongly some coals soften flow and swell then fuse and harden (Sanders, 2007). The crucible swelling number is determined by one-gram coal sample in a special crucible using gas flame up to heat temperature of 820$^0$C. Total heating time is 2 minutes 30 seconds. After this process coal will formed a button of 'coke' of a characteristics shape. The size and shaped coke will compare with in chart and given a code (Picture 3.1.3-1), ranging from 0 to 9. Metallurgical coke manufacture usually have swelling between 4 and 9. Between numbers of ½ is used to indicate the caking properties of that coal sample.



*Picture 3.1.3-1 Standard profile for the Crucible Swelling Number Test (Courtesy Standards Australia, from AS 1038.10.1) (Shekher Das, Sapna Sharma, Ratna Choudhury, 2002)*

*Size analysis:*

One of the important physical characteristics of a coal for the purpose of preparation is particle size distribution. Particle size distribution determines the selection and size of cleaning process. That will engage into the design of the coal preparation plant. Size distribution analysis method is sieving. Sieving has dry and wet sieve. Usage is depending on size analysis chosen size range. If sieving a coal into smaller than 0.5mm, then sieve going into wet sieve. Main differences of wet and dry sieving is, wet sieve is give a more real result. Most common use sieve sizes in coal plant is 50, 31.5, 16, 8, 4, 2, 1, 0.5mm. Finer fractions most common sizes are 500, 250, 125, 75, 45 micro meters.

Various tests and methods of analysis can be used to determine the principal characteristics of a coal. The two main procedures are proximate analysis and ultimate analysis. Other less common tests may be used to complement these or for special checks.

**Other Tests**

Other tests are required less frequently:

1. The breakdown of inherent and surface moisture;
2. Free-swelling index (FSI), a measure of the coking characteristics of the coal;
3. Fusion temperature of the ah;

4. Hard grove Grind Ability Index - A measure of the hardness of a coal; and
5. Alkali content of the ash.

### 3.1.4. Size Analysis

Coal samples were screened at 0.5, 0.25, 0.125, 0.063, 0.032 and 0.02 mm corresponds to 32, 60, 115, 250, 450 and 835 mesh respectively.

Size analyses of both seams are given in Table 3.1.4-1 and 3.1.4-2, shown graphically in Figures 3.1.4-1 and 3.1.4-2. Examination of these figures reveals that the all material is considerably finer than the 0.25mm material.

***Sample #1: PR7_B17_0BU:***

*Table 3.1.4-1 'Particle size analysis and assay distribution of PR7_B17_OBU' sample*

| Size range (mm) | Fractional | | | | | Cumulative retained | | |
|---|---|---|---|---|---|---|---|---|
| | Weight (%) | Ash, ad (%) | VM, ad (%) | Sulfur, ad (%) | CSN | Weight (%) | Ash (%) | Sulfur (%) |
| **+0.5** | 2 | 15.83 | 19.16 | 0.92 | 2.0 | 100 | 17.99 | 6.82 |
| **-0.5+0.25** | 35 | 16.16 | 19.69 | 1.26 | 4.5 | 98 | 18.03 | 6.70 |
| **-0.25+0.125** | 38 | 17.02 | 19.69 | 1.07 | 4.0 | 63 | 19.07 | 4.02 |
| **-0.125+0.063** | 13 | 21.71 | 19.59 | 1.21 | 4.0 | 25 | 22.18 | 1.63 |
| **-0.063+0.032** | 6 | 20.02 | 18.91 | 1.93 | 3.0 | 12 | 22.69 | 0.90 |
| **-0.032+0.020** | 2 | 18.66 | 18.69 | 1.83 | 1.0 | 7 | 21.74 | 0.40 |
| **-0.020** | 5 | 22.97 | 17.87 | 1.02 | 1.0 | 5 | 22.97 | 0.22 |
| **Total** | **100** | | | | | | | |

The average ash content for Seam 0B is 18.91% (ad),which is highest value among the Tavan Tolgoi mining seams. Average volatile matter value was 19.09% (ad). That amount of value is included coal rank of anthracite. Average crucible swelling number is 2.79. Coking coal’s CSN is between 6 and 9.

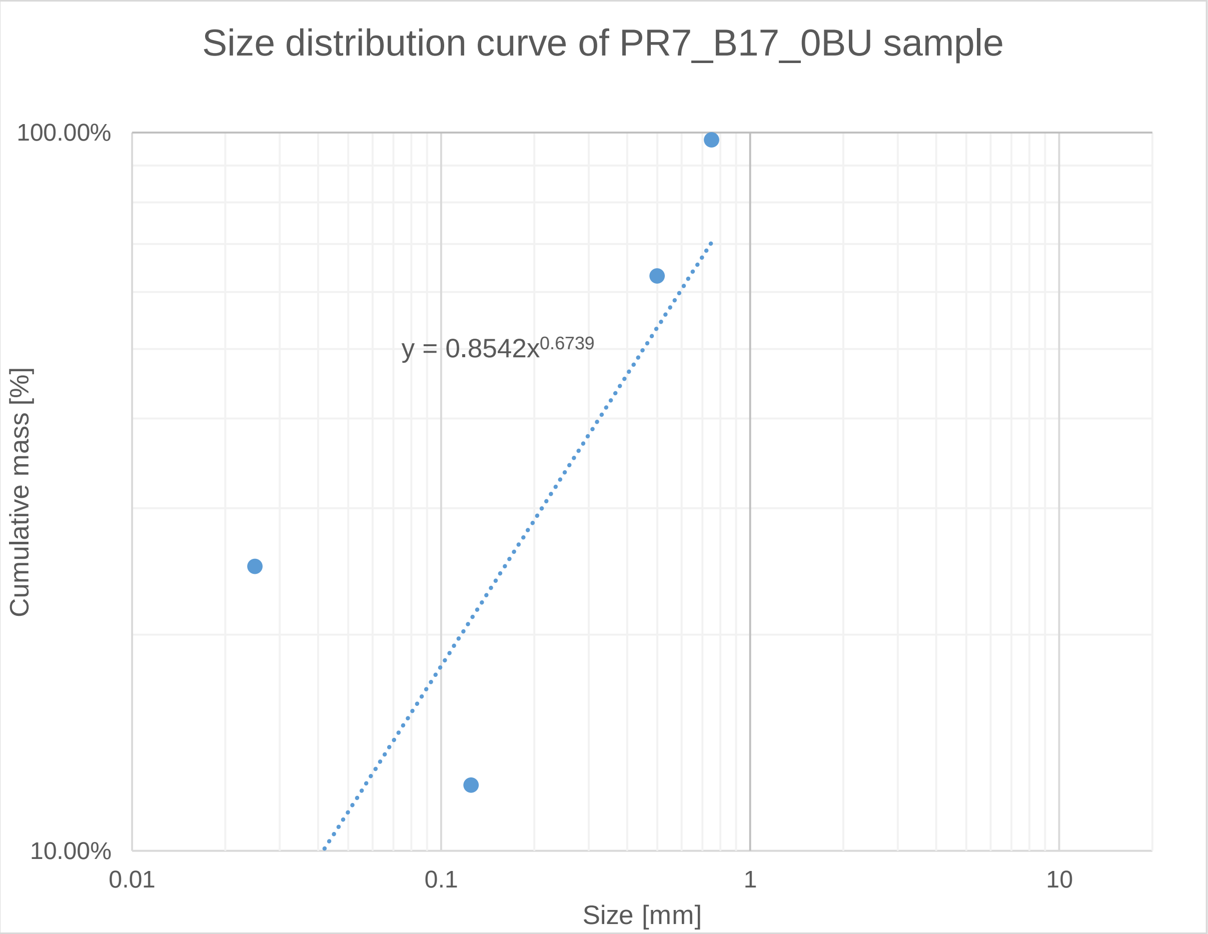


*Figure 3.1.4-1 'PR7_B17_OBU' Samples particle size distribution curve*

In figure 3.1.4-1 shown size analysis curve of first sample (PR7_B17_0BU). Using curve's equation to calculated sample P80, and P50. P80 means 80% of all coal particles below and equal that size. P50 is same as P80, but in case of 50% of all size below and equal that size value. P80 was 0.907mm, which is ≤0.907mm size of particles contains in this coal sample. P50 was 0.452mm. Same as P80, 0B seam coal sample is containing ≤0.452mm samples.

### *Sample #2: PR7_B19_0CUM:*

*Table 3.1.4-2 'PR7_B19_OCUM' samples size analysis data*

| Size range (mm) | Fractional | | | | | Cumulative retained | | |
|---|---|---|---|---|---|---|---|---|
| | Weight (%) | Ash, ad (%) | VM, ad (%) | Sulfur, ad (%) | CSN | Weight (%) | Ash (%) | Sulfur (%) |
| **+0.5** | 3 | 15.29 | 20.04 | 0.57 | 7.0 | 100 | 17.65 | 4.63 |
| **-0.5+0.25** | 43 | 16.41 | 20.31 | 0.81 | 7.5 | 97 | 17.72 | 4.52 |
| **-0.25+0.125** | 30 | 15.54 | 20.78 | 0.77 | 8.0 | 54 | 18.77 | 2.41 |
| **-0.125+0.063** | 14 | 19.46 | 20.41 | 0.84 | 6.0 | 24 | 22.81 | 0.97 |
| **-0.063+0.032** | 6 | 21.68 | 20.13 | 1.15 | 7.5 | 14 | 19.64 | 0.53 |
| **-0.032+0.020** | 2 | 18.80 | 19.37 | 0.79 | 6.0 | 8 | 18.11 | 0.19 |
| **-0.020** | 4 | 26.81 | 17.72 | 0.48 | 0.5 | 4 | 26.81 | 0.07 |
| **Total** | **100** | | | | | | | |

In table 4.1.4-2 shown quality analysis result of 0C seam sample. Average ash content value is 19.14% (ad). It gives almost same as 0B seam ash content value. Average CSN is 6.07. Which is included coking coal CSN number (6-9). Average volatile matter value is 19.82% (ad). Almost same as 0B seam volatile value.

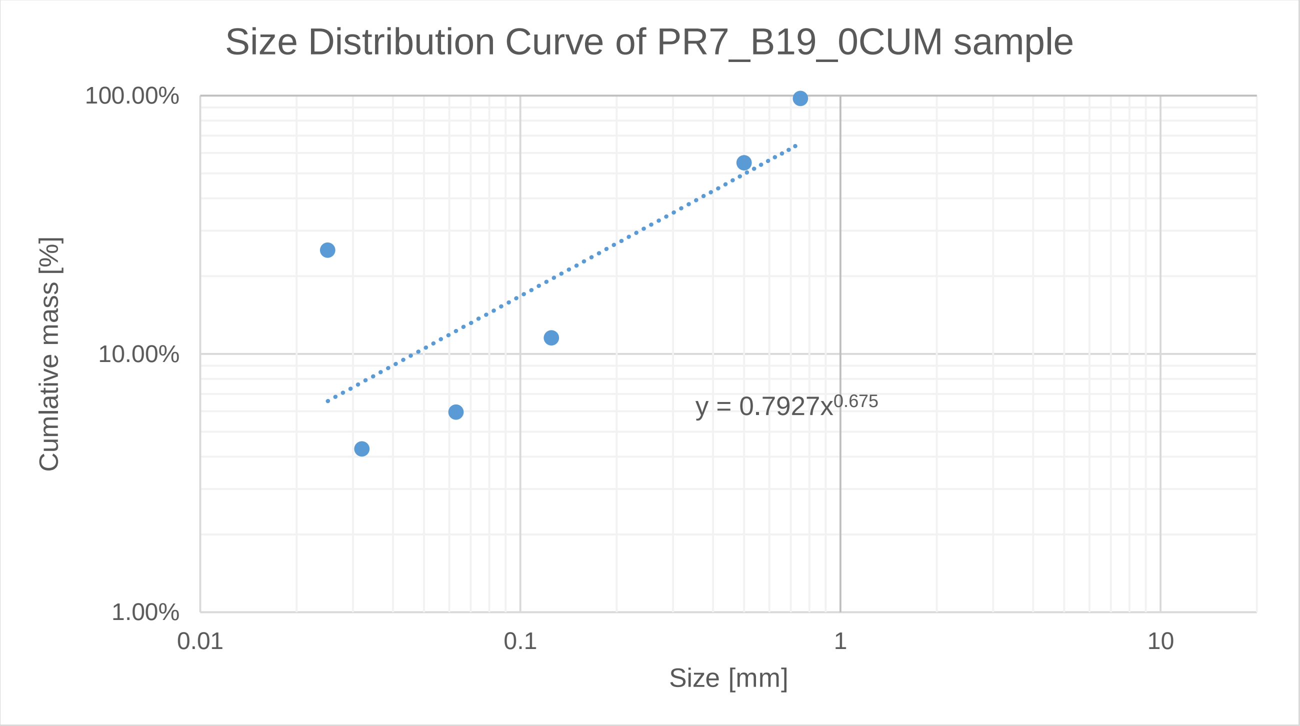


*Figure 3.1.4-2 'PR7_B19_OCUM' samples particle size distribution curve*

In figure 3.1.4-2 shown size analysis curve of second sample (PR7_B19_0CUM). P80 was

1.014mm, which is ≤1.014mm size of particles contains in this coal sample. P50 was 0.505mm. Same as P80, 0C seam coal sample is containing ≤0.505mm samples. Comparing those two samples 0C seam P80 and P50 value was higher than 0B seam. Ratio of the seam's P80 and P50 was 1.12.

## 3.2. FLOTATION EXPERIMENTAL

### 3.2.1. Equipment and Material

*:*

OC, OB seam coal samples from the Tavan Tolgoi coal deposit were used in this study. Size reduction of the coal was used a drop shutter test for Energy Resources LLC laboratory. The coal was dry sieved in plant laboratory less than 0.5mm. This coal samples used in this study.

Flotation experiment's sample preparation used following main equipment:

- Sample splitter
- Vibratory wet sieve /sieve size was 0.5, 0.25, 0.125, 0.063, 0.032, 0.020mm/
- Laboratory drier
- Crystallizing dishes /dry wet samples/

When divided sample into two section, one is going through size analysis, second one going through the flotation analysis.

Flotation test work's used equipment is:

- Laboratory flotation cell in 3-liter capacity (Picture 3.2.1-1)
- Fresh water sprayer /clean the flotation cell while flotation going/
- Fresh water containing boxes /to hold flotation cell level/
- Crystallizing dish /full fill a concentration (top products) and dry the concentration/
- Iron sheet tray /full fill a rejects (bottom products), and dry the rejects/
- Glass stirring rods /mix coal sample with flotation cell solution/

Chemicals chosen were diesel (Picture 3.2.1-3) as a collector, MIBC (Picture 3.2.1-4) as a frothier, which is using in Tavan Tolgoi coal preparation plant's flotation process. And also used comparing frothier of SNF FloMin F810, F-430, and F422 (Picture 3.2.1-2).

*Picture 3.2.1-1 Laboratory flotation machine*

*Picture 3.2.1-2 SNF FloMin F-422, F-430, and F-810 Coal flotation frothier*

*Picture 3.2.1-3 Flotation chemical of Diesel as collector*

*Picture 3.2.1-4 Flotation chemical of MIBC as a frothier*

All laboratory froth flotation test work was conducted at the Laboratory scal Flotation Machine with volume of 3 litres. Air flowrate and impeller speed was set at 1500 and 1000 rpm throughout this study.

Chemical addition was controlled with a syringe of 100 micro liter capacity. Diesel was used as the collector and methyl isobutyl carbinol (MIBC) the frothier. Throughout this study, chemical dosages are quoted in liters of kerosene per ton of feed. However, collector to frothier ratio was kept constant at a 5: 1 ratio of diesel to MIBC.

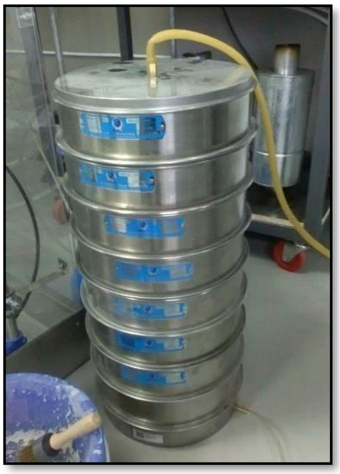
Tap water was used throughout the test work; pH of the water was not controlled as it was constant at close to neutral pH value. And also compared MIBC usage into SNF-Flomin-F422, F430, and F810 (Picture 3.2.1-2). Which is different frothier dosage was same as MIBC, but used three different frothier in same condition.

## 3.3. Method

Following flotation test work, initially each of the 0C and 0B seam samples was wet screened on 0.25mm sieve using the vibratory apparatus shown in Picture 3.3-1. Under 0.25 mm samples used into flotation test. After wet sieving dried into laboratory dryer at 80 degrees Celsius.

The flotation method contains 2 stages/phases. The purpose of stage one is to separate the floatable (concentrate) material from the non-floatable (reject) material and to deep-clean the resultant concentrate material. The stage I concentrates (top products) are feed of stage 2.

Totally 6 flotation experiments were done proceeded for this work. Phase conditions for the Flotation is shown in table 3.4-1. First flotation phase's condition and chemicals dosage was same, but only one last three flotation frothier was changed. Because of looking for effect for another frothier.



*Picture 3.3-1 Vibrating wet sieve*

*Table 3.3-1 Flotation test procedures with condition*

| Test number | Coal mass [gr] | Collector | | Frothier | | Aeration rate [m³/h] | Impeller speed [rpm] |
|---|---|---|---|---|---|---|---|
| | | Name | Dosage [ml] | Name | Dosage [ml] | | |
| **1** | 200 | Diesel | 0.66 | MIBC | 0.33 | 0.6 | 1500 |
| **2** | 200 | Diesel | 0.66 | MIBC | 0.33 | 0.6 | 1500 |
| **3** | 200 | Diesel | 0.66 | MIBC | 0.33 | 0.6 | 1500 |
| **4** | 200 | Diesel | 0.66 | F-810 | 0.33 | 0.6 | 1500 |
| **5** | 200 | Diesel | 0.66 | F-430 | 0.33 | 0.6 | 1500 |
| **6** | 200 | Diesel | 0.66 | F-422 | 0.33 | 0.6 | 1500 |

**Phase I**

Froth one:

1. Used 200 grams of the dried coals. Water mixture is approximately 10% solids by mass in a 2-liter froth cell.
2. Used impeller speed of 1500 rpm, condition the mixture for one minute.
3. Added 0.66 ml collector (diesel) and continued the conditioning for an additional two minutes.
4. Added 0.33 ml frothing chemical (MIBC, F810, F430, and F422), established an aeration rate of 0.6 $m^3$/h and impeller speed of 1500 rpm.
5. Froth the sample while continually, but gently scraped the concentrates from the cell and kept the froth cell water level essentially constant. Placed all concentration was placed in one container.
6. When froth and concentrate no longer produced (approximately 15 to 20 minutes) stopped the frothing and drained and removed the rejects from the cell (figure 3.3-1).

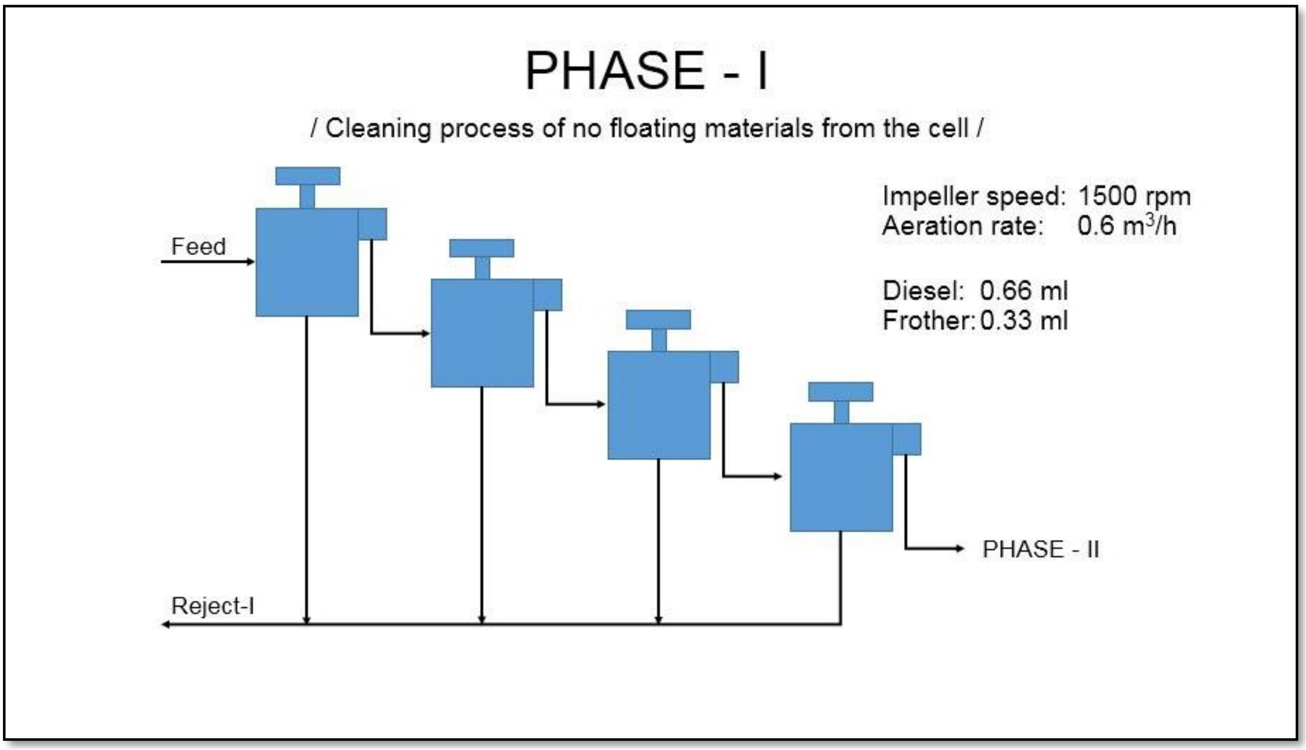


*Figure 3.3-1 Flotation Phase-I simple scheme*

Froth two:

1. Used only concentrates (top products of the Phase-I) from the Froth one. Added water to bring level up to flotation starting point. Established and aeration rate of 0.6 $m^3$/h and maintained an impeller speed of same as 1500 rpm.
2. Repeated steps 5 and 6 from Froth one.
3. Added rejects from froth two into froth one rejects.
4. Collected concentrates in one container.

Froth three:

1. Repeated as in Froth two.

Froth four:

1. Repeated as in Froth three.

**Phase II**

1. Concentrates from Phase one, added to bring a level to starting point.
2. Used an impeller speed of 1000 rpm, condition the mixture for one minutes.
3. Established an aeration rate of $0.24m^3/h$ and an impeller speed of 1000 rpm.
4. Froth the sample while continually but gently scraping the concentrates from the cell. After approximately one minute removed froth container 1 and labeled ‘Concentrate-1’.
5. Proceeded immediately to the Froth two step and repeated the froth collection according to the following table.

As you can see phase two’s condition and sequences of in picture 3.3-2

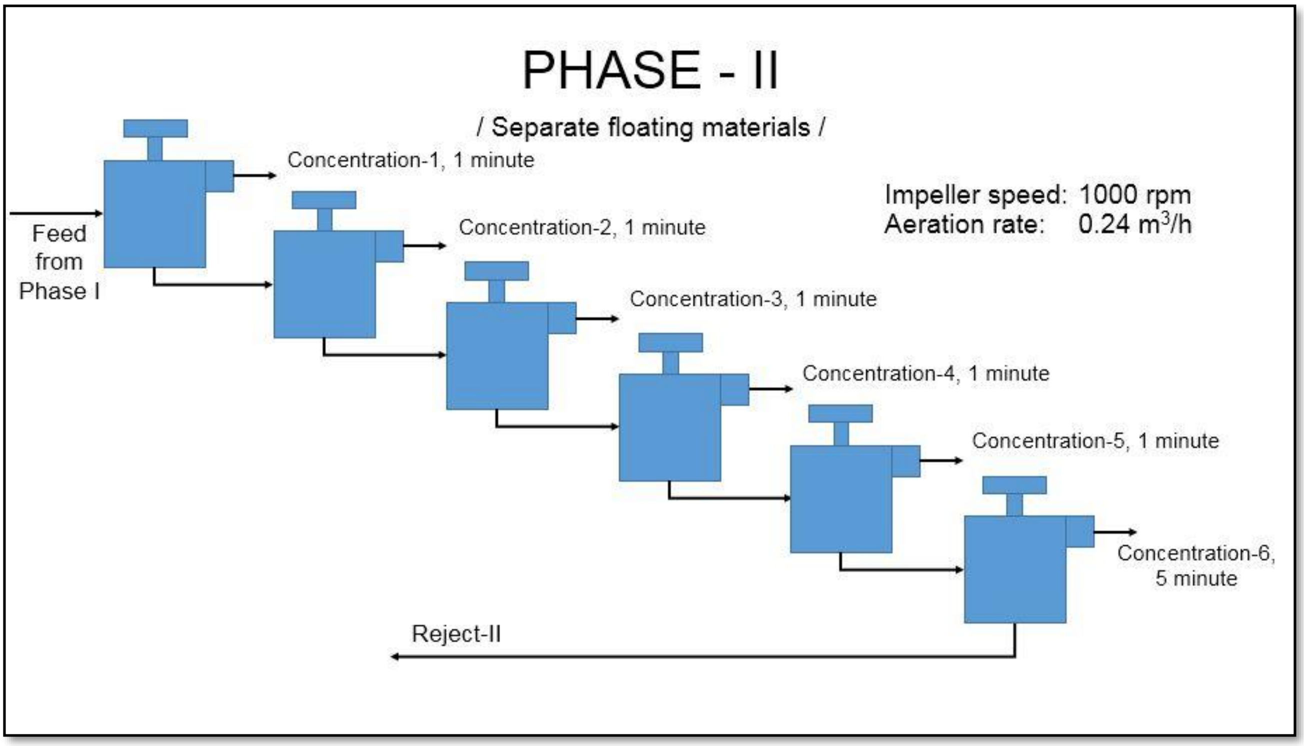
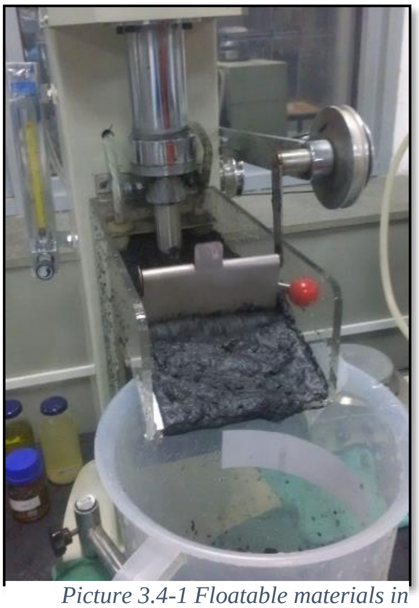


*Figure 3.3-2 Flotation Phase-II simple scheme*

After Phase-II flotation chemical main analysis done for concentrates and rejects. Which is ash content, moisture content, and volatile matter. In this study ash content, moisture content, and volatile matter content analyzes done for institute’s laboratory equipment. All analysis followed by chemical laboratory analysis method of ‘Energy Resources LLC’ (LLC, 2005).

## 3.4. Flotation test

As a mentioned 3.3 section, flotation test procedure, and phases rule. Concentration separated from Phase one is shown in Picture 3.4-1. After four times cleaning flotation's concentration used into Phase two. In totally six flotation (Table 3.3-1) did in this study work. First three flotation test work was used MIBC for frothier, and diesel for collector. Next three flotation test work; diesel was used as same as a collector, and for the frothier new reagent from SNF company "Flomin-F422, F430, and F810" were used. For single flotation test it has 6 concentrations and two rejects. After flotation product and rejects obtained from test work, they were dried in laboratory dryer in 80 degrees Celsius. The frothier dosage was kept as same as MIBC dosage, which is 0.33 ml in 3-liter flotation tank.



*Picture 3.4-1 Floatable materials in Phase one*

In Picture 3.4-2 shown 6 concentrations from Phase two. And Picture 3.4-3 shown rejects from phase one and two.

*Picture 3.4-2 Phase II, Concentrations*

*Picture 3.4-3 Phase II, Reject I and II (Left side Reject-I. Right side Reject-II)*

Flotation phases condition is shown in table 3.3-1. In Phase I all experiment conditions were kept same as each other. As mentioned before first three flotation tests were studied for optimum flotation conditions in laboratory test work. When impeller speed was set 800 rpm, reject two contains high ash coal samples as you can see in picture 3.4-3 (right side). When impeller speed was wet at low then coal particles was settled into flotation cell. Other conditions were not affected on flotation experiment. After find out optimum condition of flotation experiment, then next step was to change frothier types.

In picture 3.4-2 it has shown phase II's different concentrations of time dependence. In flotation test it was continued totally 10 minutes. After phase II was started every one minutes is should be take five sample, then last five minutes' concentration was collected into one box. Which are five samples totally. Rejects also collected two different boxes, which is phase I reject, and phase II reject.

# 4. RESULT AND DISCUSSION

## 4.1. Moisture, Ash, Volatile content

Tavan Tolgoi coal mining coal samples was carried out using three chemicals (Diesel, MIBC, Flomin F products). The effects of the chemicals evaluated with the quality analysis (moisture content, ash content, and volatile matter content). In table 4.1-1 shown quality analysis result of all flotation products.

*Table 4.1-1 Coal products quality analysis result*

| Test number | Products | Yield, ad [%] | Moisture content, ad [%] | Ash content, ad [%] | Volatile content, ad [%] |
|---|---|---|---|---|---|
| **1** | Concentrate | **88** | 0.62 | **11.78** | 21.28 |
| | Reject-I | 6 | 0.45 | 62.10 | 23.80 |
| | Reject-II | 6 | 0.75 | 38.28 | 19.20 |
| **2** | Concentrate | **57** | 0.72 | **7.78** | 22.22 |
| | Reject-I | 9 | 0.68 | 69.15 | 21.13 |
| | Reject-II | 34 | 0.63 | 26.85 | 20.25 |
| **3** | Concentrate | **56** | 0.66 | **7.89** | 22.13 |
| | Reject-I | 12 | 0.71 | 75.12 | 21.74 |
| | Reject-II | 32 | 0.61 | 35.42 | 19.34 |
| **4** | Concentrate | **56** | 0.57 | **8.47** | 22.34 |
| | Reject-I | 9 | 0.53 | 70.67 | 21.84 |
| | Reject-II | 35 | 0.54 | 16.24 | 20.04 |
| **5** | Concentrate | **53** | 0.86 | **10.64** | 21.78 |
| | Reject-I | 11 | 0.43 | 73.64 | 21.63 |
| | Reject-II | 36 | 0.48 | 19.45 | 20.42 |
| **6** | Concentrate | **51** | 0.56 | **18.70** | 21.69 |
| | Reject-I | 10 | 0.35 | 72.89 | 19.81 |
| | Reject-II | 39 | 0.58 | 15.28 | 20.72 |

It can be saying that if first three flotation test work is compared with each other, the highest yield (88%) was occurred with 11.78% ashes in the first experiment. As mentioned before the first test work's phase two condition of impeller speed was set at 900 rpm, aeration same as others as 0.24 meter cubic per hour. However, in the first test its ash content was 11.78%, which is the highest value for comparing to other flotation tests. Additionally, reject-one ash content was smaller than the comparing third experiment (7.78%). The second test's concentrate ash content was 7.78%. It was the lowest value of the all experiment. Furthermore, yield was significantly higher than the third experiment.

In case of second experiment was most comfortable to use next flotation tests. Condition of second experiment was: In phase one:

- Impeller speed of 1500 rpm
- Aeration rate is 0.6 $m^3/h$

Chemical's dosage is same as others (diesel 0.66 ml, frothiers 0.33 ml in 200 gr coals). In phase two:

- Impeller speed of 1000 rpm
- Aeration rate is 0.24 $m^3/h$.

All flotation test works results are shown in Figure 4.1-1. Concentrations minimum ash value was 7.78 in the second experiment. Frothier used as MIBC, second phase condition was set at 1000 rpm, aeration was set at same as 0.24 meter cubic per hour. Concentrate's yield was 57% (ad) and reject was 43% (ad) (Table 4.1-1).

For comparing frothier of MIBC and Flo-Min, Flo-Min frothier F-810 was lowest ash content in concentration (8.47%, ad). But MIBC lowest value was 7.78% (ad) of ash in concentration. Moreover, those frothier dosage was same as all flotation test works. When Flo-Min frothier mark increases F-4220 into F-810, while frothier efficiency was increased. Because of, as you can see in Table 4.1-1, Flo-Min reagent of F-810 lowest ash content of 8.47% in concentrate.

When got high concentrate yield, while ash content was increased. Reject's yield decreases concentrate's ash content was increasing.

Moisture and volatile matter content was did not followed different reagent usage. Highest moisture content happened in fifth flotation test in concentration (0.86% ad). Volatile matter content was same as all experiment works. Which is all experiments volatile matter same as in concentration, reject one, and reject two. In case of we could say different frothier does not highly effected on volatile matter, and moisture content.

## 4.2. Comparison of Laboratory Experiment and Industrial Flotation

In table 4.2-1 shown test work's concentrate's ash content value and coal preparation plant's ash content value. Study work's concentrate's ash content value was smaller than coal preparation plant's ash content value. Main reason is Coal plant's primary and secondary products are mixture of coarse, fine, and ultrafine circuit's products. Energy Resource LLC's ultrafine circuit's (flotation process) holding ash content values is 8-9% (ad). Just in case test work's flotation concentrate's (top product's) ash content value is same as coal preparation plant.

*Table 4.2-1 Test work's ash content value with coal preparation plant's ash content value*

| **Test work** | **Laboratory flotation experiment** | | | | | | **Coal Preparation Plant** | |
|---|---|---|---|---|---|---|---|---|
| | **C[16]-1** | **C-2** | **C-3** | **C-4** | **C-5** | **C-6** | **P[17]- 1** | **P-2** |
| **Ash, ad [%]** | 11.78 | 7.78 | 7.89 | 8.47 | 10.64 | 18.70 | **11.25** | **22.00** |

In table 4.2-2 shown ash content value of plant reject with test work. Test work's reject average ash value is 70.45% (ad). Comparing with coal preparation plant rejects value. Test work's average ash content value is approximately same as plant's coarse circuit reject. But higher than plant's fine and tailings reject ash content value. On the other hand, reject's ash content will higher, then product's ash content will low.

*Table 4.2-2 Test work's and Coal Preparation Plant's reject ash content value*

| **Test work** | **Laboratory flotation experiment** | | | | | | **Coal Preparation Plant** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **R[18]-1** | **R-2** | **R-3** | **R-4** | **R-5** | **R-6** | **Coarse reject** | **Fine reject** | **Tailings** |
| **Ash, ad [%]** | 62.10 | 69.15 | 75.12 | 70.67 | 73.64 | 72.89 | **69** | **47** | **34** |

In generally test work's concentrate's (flotation top product) ash content value was same as plant production ash content value. But flotation test work's rejects are higher ash content value than coal preparation plant's fine and tailing's ash content value.

In additionally test work's second reject's average ash content value is 35.2% (ad). It is same as coal preparation plant's tailing's ash content value. Coal preparation plant's tailing is containing reject from the flotation reject. In case of test work's flotation reject two will same as plant's flotation reject's ash content value.

Table 4.2-3 shown ash content value (ad, %) comparison of laboratory experiment and industrial laboratory result. Differences average value was 2.97, average difference percentage value was 11.81 percent. Standard deviation was 17.47. Which is average differences value was 2.97±17.47.

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[16] Concentrate (Flotation top product)

[17] Product (Energy Resource LLC, Coal Preparation Plant's product)

[18] Reject (Reject from froth flotation experiment /bottom product/ )

*Table 4.2-3 Ash content comparison of experiment result with industrial laboratory result*

| **Test number** | **Samples** | **GMIT laboratory experiment's result** | **Energy Resources LLC Laboratory result** | **Differences, [%]** |
|---|---|---|---|---|
| | | **Ash content value, ad [%]** | | |
| **1** | C | 11.78 | 12.03 | 2.12 |
| | R-1 | 62.10 | 63.39 | 2.08 |
| | R-2 | 38.28 | 34.19 | -10.68 |
| **2** | C | 7.78 | 8.63 | 10.93 |
| | R-1 | 69.15 | 71.01 | 2.69 |
| | R-2 | 26.85 | 14.62 | -45.55 |
| **3** | C | 7.89 | 8.21 | 4.06 |
| | R-1 | 75.12 | 74.66 | -0.61 |
| | R-2 | 35.42 | 21.44 | -39.47 |
| **4** | C | 8.47 | 8.80 | 3.90 |
| | R-1 | 70.67 | 71.65 | 1.39 |
| | R-2 | 16.24 | 16.05 | -1.17 |
| **5** | C | 10.64 | 9.30 | -12.59 |
| | R-1 | 73.64 | 72.63 | -1.37 |
| | R-2 | 19.45 | 16.00 | -17.74 |
| **6** | C | 18.70 | 9.32 | -50.16 |
| | R-1 | 72.89 | 73.42 | 0.73 |
| | R-2 | 15.28 | 16.11 | 5.43 |

Experimental result's main error depends test man and using equipment. Bachelor work's experiment done for GMIT laboratory. After test of ash content (ad, %) done, delivered samples into energy resources plant laboratory. Some of the sample ash content same as each other.

# 5. CONCLUSION

In this study aim was to compare reagents with each other, and compare chemical analysis into coal plant laboratory result. In experimental section done for totally six flotation process. First three flotation experiment was a, find optimum flotation condition. Flotation done for in two phases. First phase was separate floatable materials from non-floatable material. First phase's top product will feed of second phase flotation experiment. Second phase was separate concentration and rejects. Table 5-1 shown two phase's condition.

*Table 5-1 First three flotation test's condition*

| Test number | Coal mass [gr] | Collector | | Frothier | | Aeration rate [$m^3/h$] | Impeller speed [rpm] |
|---|---|---|---|---|---|---|---|
| | | Type | Dosage [ml] | Type | Dosage [ml] | | |
| **1** | 200 | Diesel | none | MIBC | none | 0.24 | 900 |
| **2** | 200 | Diesel | none | MIBC | none | 0.24 | 1000 |
| **3** | 200 | Diesel | none | MIBC | none | 0.24 | 800 |

Table 5-2 shown quality analysis result of first three flotation. Second and third one was lowest ash content (ad) value of the concentrates. In addition, yield of the second and third one were same approximately as each other (Table 5-2). On the other hand, reject's ash will increase, then concentrate ash content reduced. Because of ash content will not lost. Ash content is directly causing on coal rank. Which is ash content will small, then coal rank high.

*Table 5-2 Flotation result for first three flotation test work*

| Test number | Products | Yield, ad [%] | Ash content, ad [%] |
|---|---|---|---|
| **1** | Concentrate | **88** | **11.78** |
| | Reject-I | 6 | 62.10 |
| | Reject-II | 6 | 38.28 |
| **2** | Concentrate | **57** | **7.78** |
| | Reject-I | 9 | 69.15 |
| | Reject-II | 34 | 26.85 |
| **3** | Concentrate | **56** | **7.89** |
| | Reject-I | 12 | 75.12 |
| | Reject-II | 32 | 35.42 |

In case of last three flotation test work follows second flotation experiment condition. Which is phase one impeller speed is 1500 rpm, aeration rate is 0.6 $m^3/h$, and dosage of collector (diesel) is 0.66ml, and frothier (Flomin F-810, F-430, and F-422) is 0.33ml in 200-gram coal sample. Phase two condition is impeller speed of 1000 rpm, aeration speed is 0.24m$^3$/h. Reason of last three flotation test was compare different reagents into Tavan Tolgoi coal preparation plant's present using reagent (MIBC).

After flotation process done for quality analysis (Ash content, moisture content, and volatile matter content). Those laboratory analysis followed by Energy Resources LLC's laboratory method (LLC, 2005).

Generally high concentrate yield occurred in first flotation test (88%, ad). Concentrate's ash content was 11.78% (ad). Lowest concentrate yield (51%, ad) appears in last (test number 6) flotation experiment. Concentrate's lowest ash content (7.78%, ad) value appears in second flotation test work. Also third flotation concentrate's ash content was approximately same as very low (7.89%, ad). Second and third flotation yield was respectively 57% (ad) and 56% (ad).

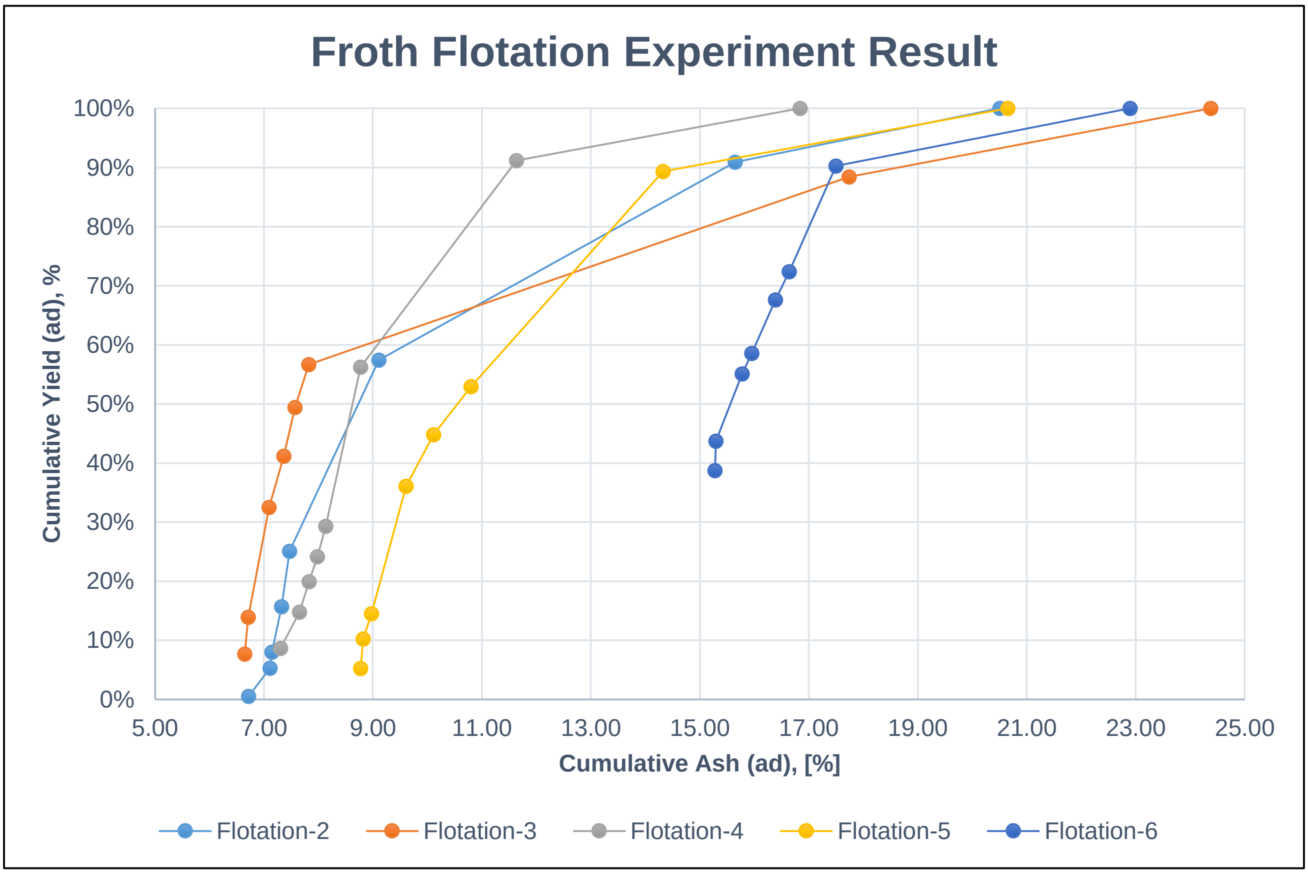

*Figure 5-2 Flotation tests result*

MIBC is the most suitable frothier for the coal compare to Flomin F-810, F-430, and F-422. Figure 5-2 shows the yield versus ash content for the concentrates and from this we found that if we keep ash content of the coal is 9% (ad)the yield of the concentrate would be 60% (ad). In case of plant could replace MIBC to FloMin F-810. Because of if using FloMin F-810 almost get same ash content (ad) in concentrate and yield. Generally, in this study work's third experiment was must suitable one. Because of when hold ash content in 9% (ad), then almost high yield will get.

IF ash content is above 9% (ad), flotation experiment number 4 will give a highest yield. If ash content is 11% (ad), then fourth test work's yield is 84% (ad). It is highest value of the other test works. Test work two and three will give concentrate yield of 67% (ad), test work five will give a yield of 55% (ad).

Energy resources LLC Coal Preparation Plant will hold flotation concentrate's ash content value of 8-9% (ad) due to to reduce ash content in final products. Coal preparation plant will discharge coking coals from coarse, fine, and ultrafine section into stockpile. Ultrafine section is generally flotation process. Coarse and fine section's yield is easily get high yield. But in flotation section high yield value follows cost. That is why plant will get high yield from coarse and fine section, then mix with ultrafine section (flotation circuit) to increase coal quality.

Main objective of this study is to figure out possibility of replacing MIBC by FloMin . So as mentioned in result and discussion part of this study, which is Flomin F product's highest efficient chemical was FloMin F-810. Assuming figure 5-2, Energy Resource LLC's present using chemical of MIBC is more comfortable to use coal preparation process. Furthermore, possible to use FloMin F-810 chemical. Reason of when plant or customers will increase product's ash content limit, then better to use FloMin F-810. Because of FloMin F-810's yield was higher than MIBC with higher ash content.

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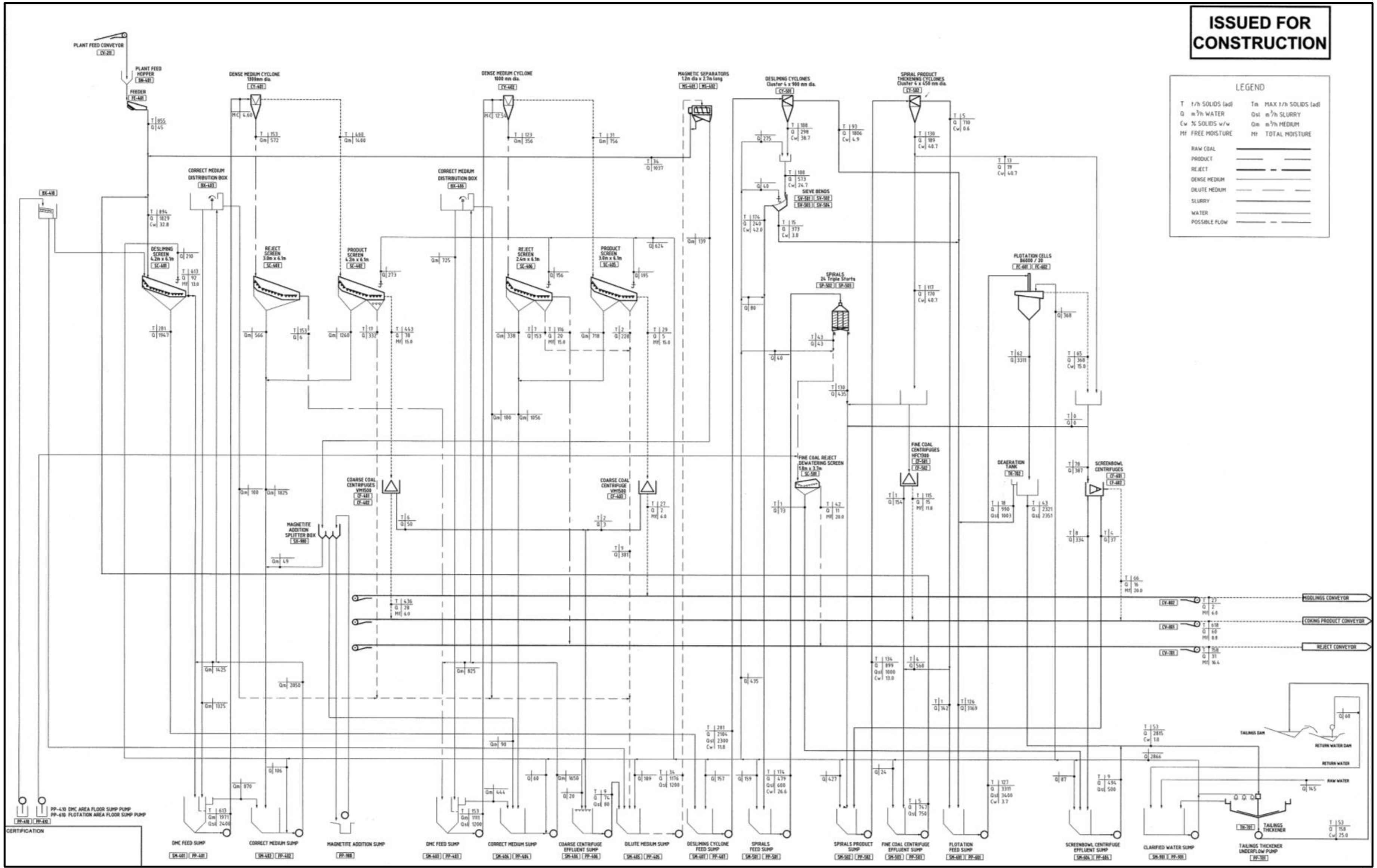
# 7. ANNEX

## 7.1. ANNEX – 1 (Energy Resources Coal Preparation Plant LLC – Process flow sheet)



## 7.2. ANNEX – 2 ('Energy Resources LLC's Chemical Analysis Method Sequences)

### Ash content

Method's equipment:

1. Weight measurement of accuracy of 0.0001 gr.
2. Crucible and high heat resistible crucible leg.
3. Laboratory incinerator

In Picture 3.3-2 you can see picture of used tools.

*Picture 7.2-1 Ash content analysis tools (left side: weight measurement, incinerator, and crucible)*

Regular method:

1. Measure empty crucible in accuracy of 0.0001 gr ($m_1$).
2. Measure sample in 1 gram. Also accuracy must be 0.0001 ($m_2$).
3. Prepare laboratory incinerator for $850^0$C in 30 minutes.
4. Open incinerator then places taken sample approximately 5 to 10 minutes (until sample finish to burn) for incinerator faces.
5. Place samples in the incinerator's main heating area. After laboratory incinerator get $815^0$C place it 40 minutes.
6. After 40 minutes take a samples then cooled it air temperature.
7. Finally measure finale sample mass ($m_3$).
8. Every samples done for pairs.
9. Result calculation done for following equation:

$$A_{ad} = \frac{m_3 - m_1}{m_2} x100$$

$A_{ad}$ – Ash content of air dry condition, %

$m_1$ – Empty crucible mass, gr

$m_2$ – Sample mass, gr

$m_3$ – After burning mass of ash with crucible, gr

*Table 7.2-1 Ash content results allowance differences*

| Ash content value($A_{ad}$) [%] | Result's allowance differences | |
|---|---|---|
| | **Correctness limit [%]** | **Allowance of correctness difference [%]** |
| **<15.00** | 0.20 | 0.30 |
| **15.00-30.00** | 0.30 | 0.50 |
| **≥30** | 0.50 | 0.70 |

### Volatile matter

Method's equipment:

1. Weight measurement of accuracy of 0.0001 gr.
2. Crucible and high heat resistible crucible leg.
3. Laboratory incinerator
4. Desiccator for cool samples.

In Picture 3.3-3 you can see picture of used tools.

*Picture 7.2-2 Volatile matter content analysis used equipment (Left side: weight measurement, crucible, laboratory incinerator, and desiccator)*

Regular method:

1. Measure empty crucible in accuracy of 0.0001 gr ($m_1$).
2. Measure sample in 1 gram. Also accuracy must be 0.0001 ($m_2$). Then cover it.
3. Prepare laboratory incinerator for $920^0$C.
4. Open incinerator then places sample 7 minutes.
5. After 4-minute furnace must be heated up to $900\pm5^0$C.
6. Finally measure finale sample mass ($m_3$).
7. Every samples done for pairs.
8. Result calculation done for following equation:

$$V_{ad} = \frac{(m_2 - (m_3 - m_1))}{m_2} x100 - Mad$$

$A_{ad}$ – Ash content of air dry condition, %

$M_{ad}$ – Analytic moisture content, %

$m_1$ – Empty crucible mass, gr

$m_2$ – Sample mass, gr

$m_3$ – After burning mass of ash with crucible, gr

*Table 7.2-2 Volatile matter content results allowance differences*

| **Volatile matter content, ($V_{ad}$) [%]** | **Result's allowance differences (calculated on the same moisture content)** | |
|---|---|---|
| | **Correctness limit [%]** | **Allowance of correctness difference [%]** |
| **<10%** | 0.3% absolute | 0.5% absolute |
| **> 10%** | Result's average 3% | 0.5% absolute or result's average 4% |

## Moisture content

Method's equipment:

1. Weight measurement of accuracy of 0.0001 gr.
2. Glass beaker with cover.
3. Laboratory drier.
4. Desiccator for cool samples.

In Picture 3.3-4 you can see picture of used tools.

*Picture 7.2-3 Analytic moisture content analysis used equipment (Left side: weight measurement, laboratory drier, and desiccator)*

Regular method:

1. Measure empty beaker with cover in accuracy of 0.0001 gr ($m_1$).
2. Measure sample in 1 gram. Also accuracy must be 0.0001 ($m_2$).
3. Prepare laboratory dryer for $105^0$C.
4. Open incinerator then places the measured sample.
5. After dryer heated up to $900\pm5^0$C. Then dry it one hour. (Anthracite coal must be dry 1.5 hours)
6. Finally measure finale sample mass ($m_3$).
7. Every samples done for pairs.
8. Result calculation done for following equation:

$$M_{ad} = \frac{(m_2 - (m_3 - m_1))}{m_2} x100$$

$M_{ad}$ – Analytic moisture content, %

$m_1$ – Empty crucible mass, gr

$m_2$ – Sample mass, gr

$m_3$ – After burning mass of ash with crucible, gr

Following table will show allowance differences between two results.

*Table 7.2-3 Analytic moisture result's allowance differences value*

| **Analytic moisture value, ($M_{ad}$) [%]** | **Allowance limitation [%]** |
|---|---|
| **5** | 0.20 |
| **5.00– 10.00** | 0.30 |
| **≥ 10** | 0.40 |

## 7.3. ANNEX – 3 ('Energy Resources LLC's Chemical Analysis Result)

| Sample name (Seam, Date, Product number) | Ash content, ad [%] |
|---|---|
| **PR7_B19_OCUU_180523_#1** | 10.09 |
| **PR7_B19_OCUU_180523_#2** | 11.47 |
| **PR7_B19_OCUU_180523_#3** | 11.35 |
| **PR7_B19_OCUU_180523_#4** | 13.33 |
| **PR7_B19_OCUU_180523_#5** | 12.59 |
| **PR7_B19_OCUU_180523_#6** | 13.35 |
| **PR7_B19_OCUU_180523_Rej_1** | 63.39 |
| **PR7_B19_OCUU_180523_Rej_2** | 34.19 |
| **PR7_B19_OCUU_180524_#1** | 7.89 |
| **PR7_B19_OCUU_180524_#2** | 7.67 |
| **PR7_B19_OCUU_180524_#3** | 9.13 |
| **PR7_B19_OCUU_180524_#4** | 8.05 |
| **PR7_B19_OCUU_180524_#5** | 9.30 |
| **PR7_B19_OCUU_180524_#6** | 7.22 |
| **PR7_B19_OCUU_180524_Rej_1** | 74.66 |
| **PR7_B19_OCUU_180524_Re_2-1** | 21.44 |
| **PR7_B19_OCUU_180524_Re_2-2** | 9.32 |
| **PR7_B19_OCUU_180525_#1** | 8.37 |
| **PR7_B19_OCUU_180525_#2** | 7.52 |
| **PR7_B19_OCUU_180525_#3** | 7.28 |
| **PR7_B19_OCUU_180525_#4** | - |
| **PR7_B19_OCUU_180525_#5** | 10.65 |
| **PR7_B19_OCUU_180525_#6** | 71.01 |
| **PR7_B19_OCUU_180525_Rej_1** | 14.69 |
| **PR7_B19_OCUU_180525_Rej_2** | 14.56 |
| **PR7_B19_OCUU_180528_#1** | 8.25 |
| **PR7_B19_OCUU_180528_#2** | 8.46 |
| **PR7_B19_OCUU_180528_#3** | 8.72 |
| **PR7_B19_OCUU_180528_#4** | 8.61 |
| **PR7_B19_OCUU_180528_#5** | 8.89 |
| **PR7_B19_OCUU_180528_#6** | 9.84 |
| **PR7_B19_OCUU_180528_Rej_1** | 71.65 |
| **PR7_B19_OCUU_180528_Rej_2** | 16.05 |
| **PR7_B19_OCUU_180529_#1** | 8.98 |
| **PR7_B19_OCUU_180529_#2** | 8.81 |
| **PR7_B19_OCUU_180529_#3** | 9.03 |

| | |
|---|---|
| **PR7_B19_OCUU_180529_#4** | 9.28 |
| **PR7_B19_OCUU_180529_#5** | 9.40 |
| **PR7_B19_OCUU_180529_#6** | 10.27 |
| **PR7_B19_OCUU_180529_Rej_1** | 72.63 |
| **PR7_B19_OCUU_180529_Rej_2** | 16.00 |
| **PR7_B19_OCUU_180530_#1** | 9.20 |
| **PR7_B19_OCUU_180530_#2** | 9.06 |
| **PR7_B19_OCUU_180530_#3** | 9.26 |
| **PR7_B19_OCUU_180530_#4** | 9.46 |
| **PR7_B19_OCUU_180530_#5** | 9.09 |
| **PR7_B19_OCUU_180530_#6** | 9.85 |
| **PR7_B19_OCUU_180530_Rej_1** | 73.42 |
| **PR7_B19_OCUU_180530_Rej_2** | 16.11 |