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Development of Coal Washability Analysis Application Thesis Progress Report

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This thesis is being undertaken under the supervision of Associate Professor Ernest Baafi, specializing in minerals industry IT related problems, Raymond Tolhurst on coal preparation technical matters, and Kevin Marston, who has expertise in both IT and mineral processing.

# Abstract

This thesis progress reports presents the progress made towards the development of an automated coal washability analysis application designed to simplify the complex and error-prone manual process of constructing coal washability curves. Coal washability analysis is critical for optimizing coal preparation processes, helping operators determine the most efficient separation densities to maximize product quality and yield. However, traditional methods rely on labour-intensive calculations that can lead to inefficiencies and inaccuracies.

The proposed application automates these calculations by leveraging modern web technologies, including React.js for the front-end interface and FastAPI for the back-end processing. The application uses the Python libraries NumPy and SciPy to handle complex mathematical computations, enabling the automated generation of washability curves from user-provided data such as ash content and specific gravity.

By offering real-time interactive visualizations of washability curves, the tool supports quick and informed decision-making for coal preparation plant operators and serves as an educational resource for students learning about coal beneficiation. This project fills a gap in the current literature by providing an accessible and cost-effective solution to washability analysis, demonstrating the potential for digital transformation in the coal industry.

# Declaration

I declare that the work in this thesis project report titled “Development of Coal Washability Analysis Application Thesis Progress Report” has been carried out by me as a port of MMMB498 subject. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis progress report is previously presented for another degree diploma at this or any institution.

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University of Wollongong, Australia

Date: 11th October 2024

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# List of Abbreviations

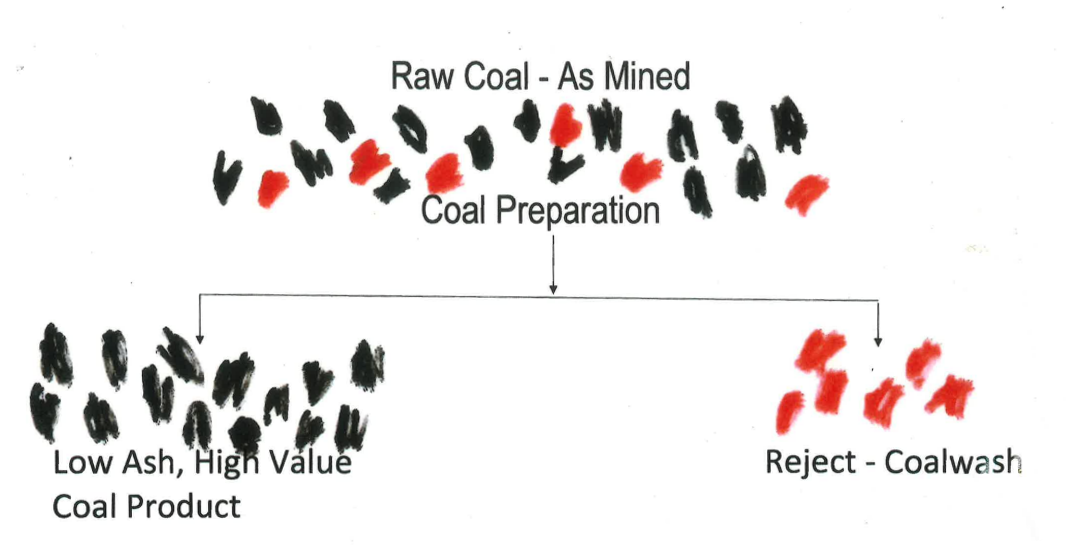
| DMS | Dense Medium Separation |
| --- | --- |
| AUD | Australian Dollar |
| SG | Specific Gravity |
| API | Application Programming Interface |
|  |  |

# Introduction

## Dense Medium Separation

Coal is a key component in many critical industries, facilitating the operation of much of our essential infrastructure (Minerals Council of Australia, 2024). For this coal to be effective in any critical application, the raw coal extracted from mines must undergo a cleaning process to remove impurities such as ash, sulphur, and moisture (Groppo, 2017). Through the removal of these impurities, the coals energy efficiency, environmental impact, and marketability are all ideally optimized (Groppo, 2017). This process of coal cleaning is known as coal beneficiation or coal washing and one of the most common techniques for this process is the dense medium separation (Groppo, 2017).

DMS utilises the differences in density between the lighter coal and shale (ash), separating out several different fractions (or products) of the raw mined coal, each with a different composition of ash (Meyer & Craig, 2014). The principle of DMS is a simple one, a bath with a density between the desired and undesired material is developed and the raw coal is added. The lighter material (lower ash content) will float, and the heavier material (higher ash content) will sink (Groppo, 2017). In general, it is also necessary for the products of the DMS process to undergo further washing in order to remove and recycle the suspension solids that are undesired for the final product (Groppo, 2017).



*Figure 1.1: Illustration of the principle of dense medium separation*

The accuracy of the separation in the DMS process is crucial for coal preparation plants in order to optimize both economic value of their products and marketability, as well as desired performance in operation (Burton, et al., 1991). Figure 1.2 shows a rough relationship between AUD value of the coal product and the ash content of the product coal. In reality, the exact value of a given coal product is very dynamic and a function of a number of variables (Lin, 2023), not just its ash content, however, this can be used as a rough guide. Figure 1.2 illustrates that a reduction in ash content of coal exponentially increase the price of the coal product.

A graph showing the value of a market

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*Figure 1.2: AUD$ per tonne of coal fraction against ash content*

For a coal preparation plant to decide on its optimized separation density, an analysis of the raw coal input must be undertaken. The analysis typically used for dense medium separation plants is a coal washability analysis (SAHU, 2013). This analysis involves the performance of sink-float tests on a representative sample of the raw coal input across a range of densities. The floats and sinks of each test are analysed to determine their ash percentage. This data can be used to produce a number of washability curves that together can allow coal preparation plant operators to make educated decisions around optimal separation densities (Tolhurst, 2024).

## The Coal Washability Curves

As ash is more dense than clean coal, the ash content of a fraction of coal increases as the density of the fraction increases (Kentucky Geological Survey, 2024). This feature can be exploited through the use of sink float trials (Kentucky Geological Survey, 2024). Small scale tests are carried out using large beakers to determine the coal ash content at different specific gravities, typically ranging from 1.3 - 1.9 SG (Tolhurst, 2024).

Starting at the light or heavy end of the beakers typically depends on where the majority of the material will be removed the earliest (Tolhurst, 2024). As samples need to be dried between, removing as much material as early as possible will reduce the time required for drying. If the lightest end is choses, the coal sample will be first placed in the beaker with the lowest specific gravity. The floats of this trial are scooped off the surface, dried, and analysed for ash content. The sinks are then strained, allowed to dry, and then added to the next beaker of increasing specific gravity. Again, the floats in the beaker are scooped off, dried and analysed and the sinks are poured through a strainer, dried, and placed into the next beaker. This is continued for the remainder of the beakers (Tolhurst, 2024).

From the results obtained from the ash content of each fraction, four washability curves can be developed (Kentucky Geological Survey, 2024):

1. The Specific Gravity Curve (Densimetric Curve)
2. The Cumulative Floats Curve
3. The Cumulative Sinks Curve
4. The Instantaneous Ash Curve

### The Specific Gravity Curve (Densimetric Curve)

The specific gravity curve (Figure 1.3) shows the relationship between the density of the separation and the yield of clean coal (floats) (Kentucky Geological Survey, 2024). Thus, if the density of separation is known, then the yield of clean coal can also be found from the graph. By convention, the specific gravity axis is typically on the top horizontal axis and the cumulative weight percentage of floats (yield of clean coal) is typically on the left vertical axis.

A graph with a line going up

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*Figure 1.3: 1.2.1. The Specific Gravity Curve (Densimetric Curve)*

### The Cumulative Floats Curve

The cumulative floats curve gives the relationship between the yield of clean coal (floats) and the ash content of the coal (Tolhurst, 2024). Thus, if the required ash content is known, then the yield or cumulative weight percentage of floats can be found from the graph. Conversely, if the yield of clean coal is known, then the expected ash content can be found from the graph. By convention, the ash content axis is typically on the bottom horizontal axis and the cumulative weight percentage of floats (yield of clean coal) is typically on the left vertical axis.

A graph with a red line

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*Figure 1.4: The Cumulative Floats Curve*

The cumulative floats curve can be used with the densimetric (specific gravity) curve. If the ash content of the clean coal yield is known, then from the cumulative floats curve, the yield can be obtained. This value for the yield can then be used to find the density of the separation required from the densimetric curve (Tolhurst, 2024).

A graph with a line going up

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*Figure 1.5: The Specific Gravity Curve (Densimetric Curve) & The Cumulative Floats Curve*

### The Cumulative Sinks Curve

The cumulative sink curve gives the relationship between the yield of sinks and the ash content of the sinks. So, if the yield of the sinks is known, then the ash content of the sinks can be found from the graph. Conversely, if the ash of the sinks is known then the yield of sinks can be found from the graph.

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*Figure 1.6: The Cumulative Sinks Curve*

The cumulative sink curve can be used with the cumulative float curve and the densimetric curve. If the ash of the floats is known, then the yield of the floats can be obtained from the cumulative floats curve. If the density is known, then the yield of floats can be obtained from the densimetric curve. In either case the yield of sinks is known, so the ash of the sinks can be found from the cumulative sinks curve.

A graph with different colored lines

Description automatically generated

*Figure 1.7: The Specific Gravity Curve (Densimetric Curve), The Cumulative Floats Curve & The Cumulative Sinks Curve*

### The Instantaneous Ash Curve (Characteristic Ash Curve)

The Instantaneous ash curve (characteristic ash curve) gives the relationship between the yield of the floats and the ash content of the particle that just floats or just sinks at that yield. It thus gives the highest ash in the floats or the lowest ash in the sinks.

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*Figure 1.8: The Cumulative Sinks Curve*

The instantaneous ash curve can be used with the other three washability curves, the specific gravity curve, the cumulative float curve, and the cumulative sink curve.

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*Figure 1.9: The Combined Coal Washability Curves*

## Problem Statement

Accurate interpretation of these washability curves is essential for coal preparations operators to determine the optimal separation densities for their desired coal products. Issues can however arise when through manual interpretation of the raw coal washability analysis data as interpretation involves manually complex mathematical calculations, which can be time-consuming and prone to error. It is here that the use of automated computer application for the analysis of this coal washability data is crucial in optimising both the quality and economic value of the final products.

The complexity of manual calculations poses several challenges:

1. **Time and Labor**: Processing large datasets of coal properties is a slow and tedious process that takes up valuable time for plant operators and engineers.
2. **Error Potential**: The manual nature of these calculations increases the likelihood of mistakes, leading to inaccurate washability curves.
3. **Educational Barriers:** For students or newcomers to coal preparation processes, understanding how to conduct and interpret washability analysis can be overwhelming without automated tools.
4. **Decision-Making Delays:** The time-consuming nature of manual calculations can delay key decision-making processes in coal preparation plants, potentially leading to inefficiencies and lower product yields

Given these challenges, there is a clear need for a modern, digital tool that can automate coal washability analysis, making it more accessible and efficient for both students and industry professionals. This project addresses that need by developing a computer-based computational model for generating coal washability curves, which eliminates the need for manual calculations.

The main goal of this project is to develop an easy-to-use application that automates coal washability calculations and provides interactive visual representations of coal washability curves. The application will serve as a resource for both students learning about coal beneficiation processes and plant operators who need to quickly and accurately determine the best strategies for coal separation.

At its core, the project seeks to address the following objectives:

1. **Automation of Washability Analysis**: The application will automate the process of generating coal washability curves based on user-provided data, such as ash content and weight percentages at various specific gravities.
2. **Interactive Visualization:** The tool will provide an intuitive, interactive interface that allows users to input data and view the resulting coal washability curves in real-time. This will enable users to understand how different separation strategies impact coal quality and yield.
3. **Reduction of Manual Calculations:** By automating the washability analysis, the tool will eliminate the need for manual mathematical calculations, saving users time and reducing the risk of errors.
4. **Enhanced Educational Resource:** For students, the application will serve as a practical learning tool, helping them understand coal preparation processes and the significance of washability analysis in industrial applications.
5. **Support for Decision-Making:** For plant operators, the application will provide a fast and reliable way to determine optimal separation strategies, aiding in decision-making and improving plant efficiency.

## Technical Approach

The proposed application will blend modern web-based technologies and data processing tools to ensure both a user-friendly product and a product that can handle the complex calculations. On the user facing (front end) side, the popular JavaScript framework React.js will be employed. React.js simplifies building dynamic user interface by using a component-based architecture (Gackenheimer, 2015). This decision will assist in management of the user input forms, washability plot visualizations, and streamlined communication with the backend system. Users will have the ability to upload a set of raw sink-float data in a range of formats and enter in the ash percentages of the coal products they desire. The integration of the JavaScript library Plotly will allow for the visualization of the washability curves in a dynamic and interactive format (Li & Bilal, 2021). This integration allows users to delve into the graphs and adjust their inputs to observe how different values impact the results.

For the backend system, the modern python-based web framework FastAPI is to be used as it is ideal for building high-performance APIs. The backend system’s primary role is to receive requests from the frontend React.js system (the raw sink-float data), provide some data processing, and return the data to be plotted. The combination of FastAPI as a backend system combined with React.js for a frontend system is quickly becoming a popular technology stack for building quick and easy web applications that are also robust and have a modern feel (Gailer, et al., 2024).

For the complex mathematical calculations and interpretations of the raw sink-float washability data, the python libraries Numpy and SciPy will be utilized. NumPy excels at efficiently handling numerical data and large arrays, while SciPy offers tools for tasks such as curve fitting and optimization (Ranjani, et al., 2019).

## Use Case Scenarios

To illustrate the practical application of the tool, the following scenario should be considered: A customer requires a Coking Coal with 9.0% ash. The coal plant operator needs to determine the yield of clean coal and the specific gravity at which the separation should occur. Using the application, the operator can input the relevant ash percentages and raw sink-float data obtained by laboratory tests, and the tool will instantly generate a coal washability curve showing the yield of clean coal and the required density of separation.

If a secondary Steaming Coal product with a 25.0% average ash can be sold, the operator can use the application to add in the second coal product and calculate the specific gravity for this separation and estimate the percentage of feed that will be recovered as Steaming Coal. The application will also provide the remaining ash percentage in the tailings, allowing the operator to evaluate the efficiency of the entire coal preparation process.

# Thesis Outline and Scope

## Aims

This project aims to produce a resource that can be used by students and coal plant operators to easily understand Coal Washability curves and avoid the need to do laborious manual mathematical calculations.

This resource is to be a computer based computational model application for calculating Coal Washability diagrams given the ash and weight percentages that float or sink at various specific gravities.

A typical use case involves answering questions like:

1. **Clean Coal Yield and Density of Separation**: Given a target ash level, the application will calculate the corresponding yield of clean coal, and the specific gravity required to achieve this separation.
2. **Secondary Coal Yield and Density**: If a secondary Coal product is to be sold with a specified ash level, the application will calculate the necessary separation density and the percentage of the feed that can be recovered.
3. **Final Tailings Analysis**: After producing multiple Coal products, the application will calculate the average ash percentage remaining in the final tailings, ensuring a complete evaluation of the coal preparation process.

The application will offer an interactive platform that not only automates complex washability calculations but also provides valuable insights into the separation process, making it an essential tool for anyone working with coal preparation.

## Deliverables

The JavaScript framework, React.js, is to be utilized to build the front end (client side) of the application. The client side should only perform the job handling user input data (plant output), communication with the backend server, and displaying the final Coal Washability curves (Doepel, 2024).

The third party, React.js package, Plotly, will be utilized to produce the final Coal Washability curves and be displayed on the react front end (Doepel, 2024).

The python framework, FastAPI, is to be utilized to build the backend (server side) of the application. The backend should receive data from the frontend, apply some processing to this data, and finally return this data to the frontend for plotting (Doepel, 2024).

The third party python packages, NumPy and SciPy, will be utilized to process data and handle data received from the frontend. These packages will process the data in such a way that yields a new dataset that can be returned to the frontend and plotted using Plotly (Doepel, 2024).

# Examples of Manual Washability Calculations and Curve Construction

The following section will walkthroughs a number of worked examples for typical washability questions a coal preparation plant may have. A walkthrough of these calculations, curve constructions and curve utilizations will illustrate the complexity of, tediousness, and margin of error present in the process and highlight the suitability for an automated approach to solve similar types of problems.

## Example 1

*Using the washability curves, cumulative floats, cumulative sinks, Instantaneous Ash and Specific Gravity Curve, by graphs, spreadsheets, estimation or other calculations, determine the outcome for the following operation.*

*Sink-Float testing of an as-mined coal has provided the results listed below.*

*Table 3-1: Example 1 Coal Washability Analysis Data*

| **Density of Separation** | **Weight %** | **Cum. Floats Wt%** | **Fraction Ash %** | **Cum. Floats Ash %** | **Cum. Sinks Wt%** | **Cum. Sinks ASh %** | **Inst. Ash Floats Yield** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| -1.3 | 8 | 8 | 2 | 2 | 92 | 31.2 | 4 |
| +1.3/1.4 | 18 | 26 | 5 | 4.1 | 74 | 37.6 | 17 |
| +1.4/1.5 | 14 | 40 | 9 | 5.8 | 60 | 42.3 | 33 |
| +1.5/1.6 | 12 | 52 | 13 | 7.5 | 48 | 52.1 | 46 |
| +1.6/1.7 | 8 | 60 | 16 | 8.6 | 40 | 59.3 | 56 |
| +1.7/1.8 | 8 | 68 | 21 | 10.1 | 32 | 68.9 | 64 |
| +1.8/1.9 | 5 | 73 | 30 | 11.4 | 27 | 76.0 | 70.5 |
| +1.9/2.0 | 3 | 76 | 37 | 12.4 | 24 | 81.0 | 74.4 |
| +2.0 | 24 | 100 | 81 | 28.9 | - | - | 88 |

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*Figure 3.1: Example 1 Washability Curves*

1. *A customer requires a Coking Coal with 9.0% Ash. What will be the yield of Clean Coal and the required density of separation?*

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*Figure 3.2: Example 1 Washability Curve 9% Ash yield of Clean Coal and required density of separation*

To find the yield of clean coal and the separation density of a 9% coking coal, the value of 9% must first be located on the x-axis of the washability curve graph. A vertical line is then drawn from this point until it intersects the cumulative floats curve. To obtain the yield of clean coal, a horizontal line is then drawn from the point to the left y-axis. This gives a value of 62% yield of clean coal.

To obtain the separation density a horizontal line is drawn from the intersection of the 9% ash vertical line, and the cumulative floats curve. This horizontal line is drawn until it intersects the densimetric curve. From this point, a vertical line can be drawn to the top x-axis. This gives a separation density of 1.725 SG.

1. *If a secondary Steaming Coal product can be sold, with a 25.0% average Ash, what will be the required density for this separation and what percentage of feed will be recovered as Steaming Coal?*

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*Figure 3.3: Example 1 required density of separation and percentage of feed for 25% ash steaming coal*

To find the required density required to produce a secondary Steaming Coal product at 25% average ash, a horizontal line can be drawn from the previous clean coal yield percentage of 62% until it intersects the characteristic ash curve. From this point a horizontal line can be drawn down to the x-axis of ash percentage. This results in a value of 20%. This value represents the lowest ash percentage of the particles that just sink from the initial separation.

To reach an average product of 25%, a maximum ash content must be found. This value will represent the highest ash percentage of the particle that just floats in the second separation.

From here, a horizontal line can be drawn up from the 30% value on the ash percentage axis until it intersects the characteristic ash curve. From here a horizontal line can be drawn until it intersects the densimetric curve. From this point, a vertical line can be drawn to the top x-axis. This gives a separation density of 1.85 SG.

To obtain the percentage of the feed that will be recovered as Steaming Coal, a horizontal line should be drawn from the 30% ash intersection of the characteristic ash curve to the left y axis. This results in a value of 70% total clean coal. This value is the combination of both the coking coal and the steaming coal feeds. To find the steaming coal feed percentage, the coking coal yield (62%) need only be subtracted from the total clean coal yield. This results in a steaming coal feed percentage of 8%.

1. *What will be the remaining average percentage Ash in the final tailings after producing both the Coking and Steaming Coals above?*

A graph with lines and numbers

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*Figure 3.4: Example 1 final tailings after producing both the Coking and Steaming Coals*

To obtain the average ash percentage of the final tailings a horizontal line is drawn from the second separation density of 1.85 SG until it intersects the densimetric curve. A horizontal line is then drawn until it intersects the cumulative sinks curve. From here, a horizontal line is drawn to the ash content on the bottom x axis. This results in an average ash percentage of the final tailings of 72.5%.

## Example 2

*Using the washability curves, cumulative floats, cumulative sinks, Instantaneous Ash and Specific Gravity Curve, by graphs, spreadsheets, estimation or other calculations, determine the outcome for the following operation.*

*Sink-Float testing of an as-mined coal has provided the results listed below.*

*Table 3-2: Example 2 Coal Washability Analysis Data*

| ***Density of Separation*** | ***Weight %*** | ***Cum. Floats Wt%*** | ***Fraction Ash %*** | ***Cum. Floats Ash %*** | ***Cum. Sinks Wt%*** | ***Cum. Sinks ASh %*** | ***Inst. Ash Floats Yield*** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *-1.3* | *28* | *28* | *1.9* | *1.9* | *72* | *27.4* | *14* |
| *+1.3/1.4* | *23* | *51* | *3.2* | *2.5* | *49* | *38.8* | *39.5* |
| *+1.4/1.5* | *14* | *65* | *9.1* | *3.9* | *35* | *50.7* | *58* |
| *+1.5/1.6* | *6* | *71* | *14.3* | *4.8* | *29* | *58.2* | *68* |
| *+1.6/1.7* | *3* | *74* | *26.4* | *5.7* | *26* | *61.9* | *72.5* |
| *+1.7/1.8* | *4* | *78* | *33* | *7.1* | *22* | *67.1* | *76* |
| *+1.8* | *22* | *100* | *67.1* | *20.3* | *-* | *-* | *89* |

**A graph with lines and numbers

Description automatically generated**

*Figure 3.5: Example 2 Washability Curves*

1. *A customer requires a Coking Coal with 5.0% Ash. What will be the yield of Clean Coal and the required density of separation?*

A graph with lines and numbers

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*Figure 3.6: Example 2 Washability Curve 5% Ash yield of Clean Coal and required density of separation*

To find the yield of clean coal and the separation density of a 5% coking coal, the value of 5% must first be located on the x-axis of the washability curve graph. A vertical line is then drawn from this point until it intersects the cumulative floats curve. To obtain the yield of clean coal, a horizontal line is then drawn from the point to the left y-axis. This gives a value of 72% yield of clean coal.

To obtain the separation density a horizontal line is drawn from the intersection of the 5% ash vertical line, and the cumulative floats curve. This horizontal line is drawn until it intersects the densimetric curve. From this point, a vertical line can be drawn to the top x-axis. This gives a separation density of 1.64 SG.

1. *If a secondary Steaming Coal product can be sold, with a 30.0% average Ash, what will be the required density for this separation and what percentage of feed will be recovered as Steaming Coal?*

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Description automatically generated

*Figure 3.7: Example 2 required density of separation and percentage of feed for 30% ash steaming coal*

To find the required density required to produce a secondary Steaming Coal product at 30% average ash, a horizontal line can be drawn from the previous clean coal yield percentage of 72% until it intersects the characteristic ash curve. From this point a horizontal line can be drawn down to the x-axis of ash percentage. This results in a value of 25%. This value represents the lowest ash percentage of the particles that just sink from the initial separation.

To reach an average product of 30%, a maximum ash content must be found. This value will represent the highest ash percentage of the particle that just floats in the second separation.

From here, a horizontal line can be drawn up from the 35% value on the ash percentage axis until it intersects the characteristic ash curve. From here a horizontal line can be drawn until it intersects the densimetric curve. From this point, a vertical line can be drawn to the top x-axis. This gives a separation density of 1.775 SG.

To obtain the percentage of the feed that will be recovered as Steaming Coal, a horizontal line should be drawn from the 35% ash intersection of the characteristic ash curve to the left y axis. This results in a value of 77% total clean coal. This value is the combination of both the coking coal and the steaming coal feeds. To find the steaming coal feed percentage, the coking coal yield (72%) need only be subtracted from the total clean coal yield. This results in a steaming coal feed percentage of 5%.

1. *What will be the remaining average percentage Ash in the final tailings after producing both the Coking and Steaming Coals above?*

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*Figure 3.8: Example 2 final tailings after producing both the Coking and Steaming Coals*

To obtain the average ash percentage of the final tailings a horizontal line is drawn from the second separation density of 1.775 SG until it intersects the densimetric curve. A horizontal line is then drawn until it intersects the cumulative sinks curve. From here, a horizontal line is drawn to the ash content on the bottom x axis. This results in an average ash percentage of the final tailings of 66%.

## Example 3

*Using the washability curves, cumulative floats, cumulative sinks, Instantaneous Ash and Specific Gravity Curve, by graphs, spreadsheets, estimation or other calculations, determine the outcome for the following operation.*

*Sink-Float testing of an as-mined coal has provided the results listed below.*

*Table 3-3: Example 3 Coal Washability Analysis Data*

| ***Density of Separation*** | ***Weight %*** | ***Cum. Floats Wt%*** | ***Fraction Ash %*** | ***Cum. Floats Ash %*** | ***Cum. Sinks Wt%*** | ***Cum. Sinks ASh %*** | ***Inst. Ash Floats Yield*** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *-1.3* | *25* | *25* | *2* | *2* | *75* | *31.6* | *12.5* |
| *+1.3/1.4* | *20* | *45* | *4* | *2.9* | *55* | *41.6* | *35* |
| *+1.4/1.5* | *10* | *55* | *9* | *4* | *45* | *48.9* | *50* |
| *+1.5/1.6* | *10* | *65* | *15* | *5.7* | *35* | *58.6* | *60* |
| *+1.6/1.7* | *5* | *70* | *27* | *7.2* | *30* | *63.8* | *67* |
| *+1.7/1.8* | *5* | *75* | *33* | *8.9* | *25* | *70* | *72* |
| *+1.8* | *25* | *100* | *70* | *24.2* | *-* | *-* | *87.5* |

A graph with lines and numbers

Description automatically generated

*Figure 3.9: Example 3 Washability Curves*

1. *A customer requires a Coking Coal with 5.0% Ash. What will be the yield of Clean Coal and the required density of separation?*

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*Figure 3.10: Example 3 Washability Curve 5% Ash yield of Clean Coal and required density of separation*

To find the yield of clean coal and the separation density of a 5% coking coal, the value of 5% must first be located on the x-axis of the washability curve graph. A vertical line is then drawn from this point until it intersects the cumulative floats curve. To obtain the yield of clean coal, a horizontal line is then drawn from the point to the left y-axis. This gives a value of 61% yield of clean coal.

To obtain the separation density a horizontal line is drawn from the intersection of the 5% ash vertical line, and the cumulative floats curve. This horizontal line is drawn until it intersects the densimetric curve. From this point, a vertical line can be drawn to the top x-axis. This gives a separation density of 1.56 SG.

1. *If a secondary Steaming Coal product can be sold, with a 22.0% average Ash, what will be the required density for this separation and what percentage of feed will be recovered as Steaming Coal?*

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*Figure 3.11: Example 3 required density of separation and percentage of feed for 22% ash steaming coal*

To find the required density required to produce a secondary Steaming Coal product at 22% average ash, a horizontal line can be drawn from the previous clean coal yield percentage of 61% until it intersects the characteristic ash curve. From this point a horizontal line can be drawn down to the x-axis of ash percentage. This results in a value of 17%. This value represents the lowest ash percentage of the particles that just sink from the initial separation.

To reach an average product of 22%, a maximum ash content must be found. This value will represent the highest ash percentage of the particle that just floats in the second separation.

From here, a horizontal line can be drawn up from the 22% value on the ash percentage axis until it intersects the characteristic ash curve. From here a horizontal line can be drawn until it intersects the densimetric curve. From this point, a vertical line can be drawn to the top x-axis. This gives a separation density of 1.66 SG.

To obtain the percentage of the feed that will be recovered as Steaming Coal, a horizontal line should be drawn from the 27% ash intersection of the characteristic ash curve to the left y axis. This results in a value of 68% total clean coal. This value is the combination of both the coking coal and the steaming coal feeds. To find the steaming coal feed percentage, the coking coal yield (61%) need only be subtracted from the total clean coal yield. This results in a steaming coal feed percentage of 7%.

1. *What will be the remaining average percentage Ash in the final tailings after producing both the Coking and Steaming Coals above?*

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*Figure 3.12: Example 3 final tailings after producing both the Coking and Steaming Coals*

To obtain the average ash percentage of the final tailings a horizontal line is drawn from the second separation density of 1.66 SG until it intersects the densimetric curve. A horizontal line is then drawn until it intersects the cumulative sinks curve. From here, a horizontal line is drawn to the ash content on the bottom x axis. This results in an average ash percentage of the final tailings of 61%.

## Example 4

*Using the washability curves, cumulative floats, cumulative sinks, Instantaneous Ash and Specific Gravity Curve, by graphs, spreadsheets, estimation or other calculations, determine the outcome for the following operation.*

*Sink-Float testing of an as-mined coal has provided the results listed below.*

*Table 3-4: Example 4 Coal Washability Analysis Data*

| ***Density of Separation*** | ***Weight %*** | ***Cum. Floats Wt%*** | ***Fraction Ash %*** | ***Cum. Floats Ash %*** | ***Cum. Sinks Wt%*** | ***Cum. Sinks ASh %*** | ***Inst. Ash Floats Yield*** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *-1.3* | *10* | *10* | *2* | *2* | *90* | *27.5* | *5* |
| *+1.3/1.4* | *30* | *40* | *4* | *3.5* | *60* | *39.3* | *25* |
| *+1.4/1.5* | *18* | *58* | *11.6* | *6* | *42* | *51.2* | *49* |
| *+1.5/1.6* | *12* | *70* | *23.5* | *9* | *30* | *62.3* | *64* |
| *+1.6/1.7* | *7* | *77* | *36.6* | *11.5* | *23* | *70.2* | *73.5* |
| *+1.7/1.8* | *5* | *82* | *51.6* | *14* | *18* | *75.1* | *79.5* |
| *+1.8/1.9* | *2* | *84* | *56* | *15* | *16* | *77.5* | *83* |
| *+1.9* | *16* | *100* | *77.5* | *25* |  |  | *92* |

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*Figure 3.13: Example 4 Washability Curves*

1. *A customer requires a Coking Coal with 7.0% Ash. What will be the yield of Clean Coal and the required density of separation?*

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*Figure 3.14: Example 3 Washability Curve 7% Ash yield of Clean Coal and required density of separation*

To find the yield of clean coal and the separation density of a 7% coking coal, the value of 7% must first be located on the x-axis of the washability curve graph. A vertical line is then drawn from this point until it intersects the cumulative floats curve. To obtain the yield of clean coal, a horizontal line is then drawn from the point to the left y-axis. This gives a value of 61% yield of clean coal.

To obtain the separation density a horizontal line is drawn from the intersection of the 5% ash vertical line, and the cumulative floats curve. This horizontal line is drawn until it intersects the densimetric curve. From this point, a vertical line can be drawn to the top x-axis. This gives a separation density of 1.54 SG.

1. *If a secondary Steaming Coal product can be sold, with a 28.0% average Ash, what will be the required density for this separation and what percentage of feed will be recovered as Steaming Coal?*

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*Figure 3.15: Example 4 required density of separation and percentage of feed for 28% ash steaming coal*

To find the required density required to produce a secondary Steaming Coal product at 28% average ash, a horizontal line can be drawn from the previous clean coal yield percentage of 62% until it intersects the characteristic ash curve. From this point a horizontal line can be drawn down to the x-axis of ash percentage. This results in a value of 22%. This value represents the lowest ash percentage of the particles that just sink from the initial separation.

To reach an average product of 28%, a maximum ash content must be found. This value will represent the highest ash percentage of the particle that just floats in the second separation.

From here, a horizontal line can be drawn up from the 34% value on the ash percentage axis until it intersects the characteristic ash curve. From here a horizontal line can be drawn until it intersects the densimetric curve. From this point, a vertical line can be drawn to the top x-axis. This gives a separation density of 1.62 SG.

To obtain the percentage of the feed that will be recovered as Steaming Coal, a horizontal line should be drawn from the 34% ash intersection of the characteristic ash curve to the left y axis. This results in a value of 71% total clean coal. This value is the combination of both the coking coal and the steaming coal feeds. To find the steaming coal feed percentage, the coking coal yield (62%) need only be subtracted from the total clean coal yield. This results in a steaming coal feed percentage of 9%.

1. *What will be the remaining average percentage Ash in the final tailings after producing both the Coking and Steaming Coals above?*

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*Figure 3.16: Example 4 final tailings after producing both the Coking and Steaming Coals*

To obtain the average ash percentage of the final tailings a horizontal line is drawn from the second separation density of 1.62 SG until it intersects the densimetric curve. A horizontal line is then drawn until it intersects the cumulative sinks curve. From here, a horizontal line is drawn to the ash content on the bottom x axis. This results in an average ash percentage of the final tailings of 65%.

# Literature Review

Studies into coal washability are critical to the pursuit for optimization of both the coal preparation process and the coal products, and key to improving the coal preparation plant efficiency. A number of researchers have dedicated time and effort to exploring various techniques and technologies, contributing to the development of methods to enhance the reduction of ash and other impurities in the final coal products. However, despite significant advancements, there remain challenges in achieving consistent and reliable results across different coal types, particularly when manual methods are used. An analysis of the research has been discussed, emphasising key developments in both traditional technologies and recent innovations that have facilitated the automation applications proposed in this report.

## Traditional Washability Analysis Techniques

In Rao’s paper “Washability characteristics of low-volatile bituminous coal from the Bering River field, Alaska” (RAO, 1969) a succinct demonstration of the effectiveness of coal washability is showcased. This paper was a foundational study for coal washing particularly to meet metallurgical standards. Rao’s techniques relive extensively on labour intensive calculations and plotting of the combined washability curves. Whist these manually constructed curves can be accurate for small samples, they are less practical for larger scale operation of coal preparation plants. Charan and their team offer a similar investigation in their paper “Cleaning Potential of Samleshwari Noncoking Coal by Washability Investigation” (Charan, et al., 2007) emphasising the effectiveness of the coal washability analysis, this time, focusing on non-coking coal products. An adequate yield of product coal was achieved, however, the methods used encountered the same limitations Rao had previously seen due to the manual construction of the washability curves.

Mohanty and their team adopted innovative flotation techniques in order to optimise separation in their paper “Coal Flotation Washability: Development of an Advanced Procedure” (MOHANTY, et al., 1998). Whist these techniques offered some optimization in separation, manual interpretation of the sink-float test data was still required and has remained the standard practice in the industry. This continues to limit the efficiently of the coal preparation process in such a fast-paced industry.

These studies demonstration a foundation on the coal washability analysis techniques used in industry today and expose the need for an automated solution.

## The Need for Automation in Washability Analysis

Much of the focus in the area of coal preparation has been on the limitations of the traditional analysis methods through automation. Abbott and Miles propose a mathematical method for interpolating and smoothing the cumulative floats curve using M-curves in their paper “Smoothing and interpolation of float/sink data for coals” (Abbott & Miles, 1991). This solution offers a great approach for coal washability prediction, however, is still computationally heavy, without the use of an automated application. The M-curve approach offers a significant improvement into traditional methods of interpretation of coal washability analysis data.

Previously, Bowen, Jowett, and Smith had introduced similar methods of curve fitting and interpolation using hyperbolic equations in their paper “A Curve Fitting Aid to Coal Cleaning System Optimization” (Bowen, et al., 1985). heir approach enabled more precise predictions of cleaning potential, streamlining the calculation of separation densities and yields. While their method simplified some aspects of coal washability analysis, it still relied on manual input and interpretation, which limited its efficiency in real-world applications. This highlights the ongoing need for fully automated solutions that can process and analysis data with minimal human intervention.

Salama (1998) contributed to the development of new graphical methods for evaluating washability characteristics, introducing the CM-curve to complement the M-curve. His washability characteristics index (WI), which quantified the washability of different coal samples, made it easier to compare coals on a uniform basis. However, while Salama’s method simplified the graphical interpretation of washability data, it did not address the computational challenges of handling large datasets or integrating real-time analysis into coal preparation plants.

## Recent Advances in Automated Coal Washability Analysis

The push for real-time, automated analysis of coal washability has gained momentum in recent years, particularly with the advent of digital image processing and neural networks. Ze-lin et al. (2011) proposed a MATLAB-based image recognition system that predicts coal washability curves by analyzing particle images. While this approach achieved a high degree of accuracy, with total ash prediction errors of just 2.375%, it still exceeded China's national coal preparation standards in some cases. This demonstrates both the potential and limitations of modern automation techniques, highlighting the need for further refinement of digital tools.

Lin et al. (2000) made significant contributions with their work on X-ray computed tomography (CT) for washability analysis. Their system offered a non-invasive way to assess coal properties, improving the speed and accuracy of washability predictions. However, the high cost and complexity of CT technology made it less accessible to smaller coal processing plants, limiting its widespread adoption.

## Gaps in the Literature and the Need for a Practical Solution

While recent advancements have improved the precision and speed of coal washability analysis, there is still a gap in the availability of user-friendly, cost-effective tools that can be easily integrated into both educational and industrial settings. The majority of existing systems, such as Ze-lin's neural network approach and Lin's CT-based analysis, require specialized equipment or expertise, which can be a barrier for smaller operations or students learning about coal preparation.

This thesis aims to address this gap by developing an accessible, automated tool that simplifies coal washability calculations. By leveraging modern web technologies such as React, FastAPI, and Python libraries like NumPy and SciPy, the proposed system will automate the generation of washability curves, reducing the need for manual calculations. Unlike more complex or expensive solutions, this application will be easy to use and adaptable to various coal types, making it a valuable resource for both students and industry professionals.

# Design

The coal washability analysis application will be built using a combination of modern web development and data processing technologies, ensuring it is both user-friendly and powerful enough to handle complex calculations.

The front end of the application will be developed using React, a popular JavaScript library for building dynamic user interfaces. React’s component-based architecture will make it easier to manage the input forms, visualizations, and communication with the backend server. Users will be able to input data such as ash percentages and specific gravity values through an intuitive interface. The visualizations, which will include the coal washability curves, will be generated using Plotly, a powerful charting library that integrates seamlessly with React. Plotly’s interactive features will allow users to explore the washability curves in detail and adjust their inputs to see how different values affect the outcomes.

The backend will be powered by FastAPI, a modern Python framework designed for building high-performance APIs. FastAPI’s asynchronous capabilities will ensure that the application can handle multiple requests simultaneously, improving the overall speed and responsiveness of the system. The backend’s main role will be to receive data from the front end, process it using specialized libraries, and return the results for visualization.

To handle the complex mathematical calculations involved in washability analysis, the backend will utilize two well-established Python libraries: NumPy and SciPy. NumPy is known for its efficient handling of numerical data, particularly large arrays, while SciPy provides additional tools for performing mathematical operations such as curve fitting, interpolation, and optimization. These libraries will work together to transform the raw data provided by users into accurate washability curves, taking into account factors such as ash content, weight distribution, and specific gravity.

Users will be able to input key variables such as the desired ash content for a product Coal, weight percentages, and specific gravity values. The application will then perform the necessary calculations and return output values such as the yield of clean coal, the required separation density, and the ash content in the final tailings. The resulting data will be displayed as an interactive graph on the front end, allowing users to explore various separation scenarios.

Figure 5.1 showcases a preliminary design of the user interface for the application. Key features of this design include:

1. **A file input element:** This will allow the user to in input and upload their dataset collected from a sink-float analysis of their coal sample.
2. **Product ash percentage text inputs:** This shall allow the used to select a desired average ash percentage for their desired coal product/s.
3. **Button to add additional coal products:** This will allow the user to flag to the model that an additional coal product is required and to provide an additional text input for the average ash percentage of this additional coal product.
4. **Interactive plot of the combined washability curves:** This will display the required densities of separation for each coal product.

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*Figure 5.1: Application UI*

Figure 5.2 illustrates a high level of the system architecture for the coal washability analysis application.

A diagram of a computer flowchart

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*Figure 5.2: System Architecture*

## Backend Calculations

The application will require 3 variables for each fraction data point:

1. The Specific Gravity of the Fraction. [A]
2. The Weight of the Fraction the floats. [B]
3. Ash percentage of the fraction that floats. [E]

From these values, all other relevant data points can be calculated in order to produce the washability curves. The application structures the data as a pandas dataframe for simplicity and data manipulation. Assuming the raw input data is stored in the file data.csv, the data shall be into the application as shown below.

import pandas as pd

data = pd.read\_csv('Data/raw1.csv')

First the weight percent of each fraction [C] should be calculated. This will be the weight of the fraction the floats divided by the total weight of the fraction (Tolhurst, 2024).

data['C'] = data['B'] / data['B'].sum() \* 100

The cumulative weight percentage [D] can then be calculated through a sum of the weight percent fractions (Tolhurst, 2024).

data['D'] = data['C'].cumsum()

To calculate the weight of the ash fraction as a percentage of the total weight [F], the fraction weight is multiplied by the ash percentage in the fraction (Tolhurst, 2024).

data['F'] = data['C'] \* data['E'] / 100

The cumulative weight percentage of the ash [G] can then be calculated through a sum of the weight percent fractions (Tolhurst, 2024).

data['G'] = data['F'].cumsum()

The cumulative floats ash [H] can then be calculated by dividing the cumulative weight percentage of the ash by the weight of the ash fraction as a percentage of the total weight (Tolhurst, 2024).

data['H'] = data['G'] / data['D'] \* 100

The sink weight percentage of ash [I] is calculated from the total ash percentage minus the ash in the cumulative floats (Tolhurst, 2024).

data['I'] = data['F'].sum() - data['G']

The cumulative sinks weight percent [J] can be calculated by subtracting the cumulative weight percentage by 100 (Tolhurst, 2024).

data['J'] = 100 - data['D']

The cumulative sinks ash percentage [K] can be calculated by dividing the sink weight percentage of ash by the cumulative sinks weight percent (Tolhurst, 2024).

data['K'] = data['I'] / data['J'] \* 100

The heaviest floats percentage with that ash percentage [M] can be calculated by (Tolhurst, 2024):

data['M'] = None

for i, row in data.iterrows():

    if i == 0:

        data['M'][i] = data['C'][i] / 2

    else:

        data['M'][i] = data['D'][i-1] + data['C'][i] / 2

Following this calculation, libraries such as Numpy and SciPy will be utilized to perform interpolation and curve fitting of the data.

# Progress

See appendix for meeting discussion notes.

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*Figure 6.1: Thesis Progress Gantt Chart*

# Conclusion

The development of an automated process to the calculations and construction of washability curves addresses a gap both as an educational resource, as well as a tool to be utilized by coal preparation plants. By leveraging modern web technologies, this application will simplify the traditional approach and minimise the errors in constructing coal washability curves. The application aims to optimise both the time, and the labour involved, making it an asset to any coal preparation plant. Moving forward, development work can begin to take place with the design presented.

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# Appendix

## Meeting 2 Discussion Notes

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## Meeting 4 Discussion Notes

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## Meeting 5 Discussion Notes

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