Coal blending and process redesign for a steam generation plant

by

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Abstract

Modern society has become more reliant on electricity, as more electrical conveniences are added to both home and workplace. This demand for electricity has resulted in the burning of large quantities of coal to produce a portion of the electricity needed. A byproduct of the combustion process is the resultant fly ash (incombustible mineral matter) that is left after all the organic components of coal have been consumed or driven off during combustion. An abundance of ash in the coal during the combustion process can impede the electricity generation process. This report seeks to highlight development into reducing the ash content of coal through coal blending processes, using ash scanning technology.

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1 Introduction and Background

1.1 Motivation

Boiler tube failures are a major cause of power outages world-wide. These failures are also the cause of outages of the Infrachem boilers at Sasol in Sasolburg. In addition, many boiler tubes have to be replaced due to surface degradation. It was established that erosion due to fly-ash impingement is the main cause of boiler tube surface degradation.

The present generation has become more reliant on electricity, as more and more amenities are added to both home and workplace. This demand for electricity has led to large quantities of coal being consumed to produce a portion of the electricity needed. A byproduct of the burning process is the resultant fly ash (incombustible mineral matter) that is left after all the organic components (fixed carbon) of coal have been consumed. Scheetz and Earle (1998) state that for every ton of coal burned, in general between 3 and 35% of the mass remains after combustion as fly ash.

According to Kloppers (1999) South Africa mostly uses the pulverized-coal-fired boiler method to produce electricity. Boiler efficiency is highly dependent on the correct utilization of the knowledge of ash content of the coals fed into it. This makes ash content determination a vital part of electricity generation.

Tube failures, leading to power outages, have occurred more frequently during the past few years. This problem has led to Sasol's sponsorship of this research project to investigate boiler tube surface degradation and methods of reducing coal ash content.

1.2 Background of Sasol Mining

1.2.1 Sasol Mining

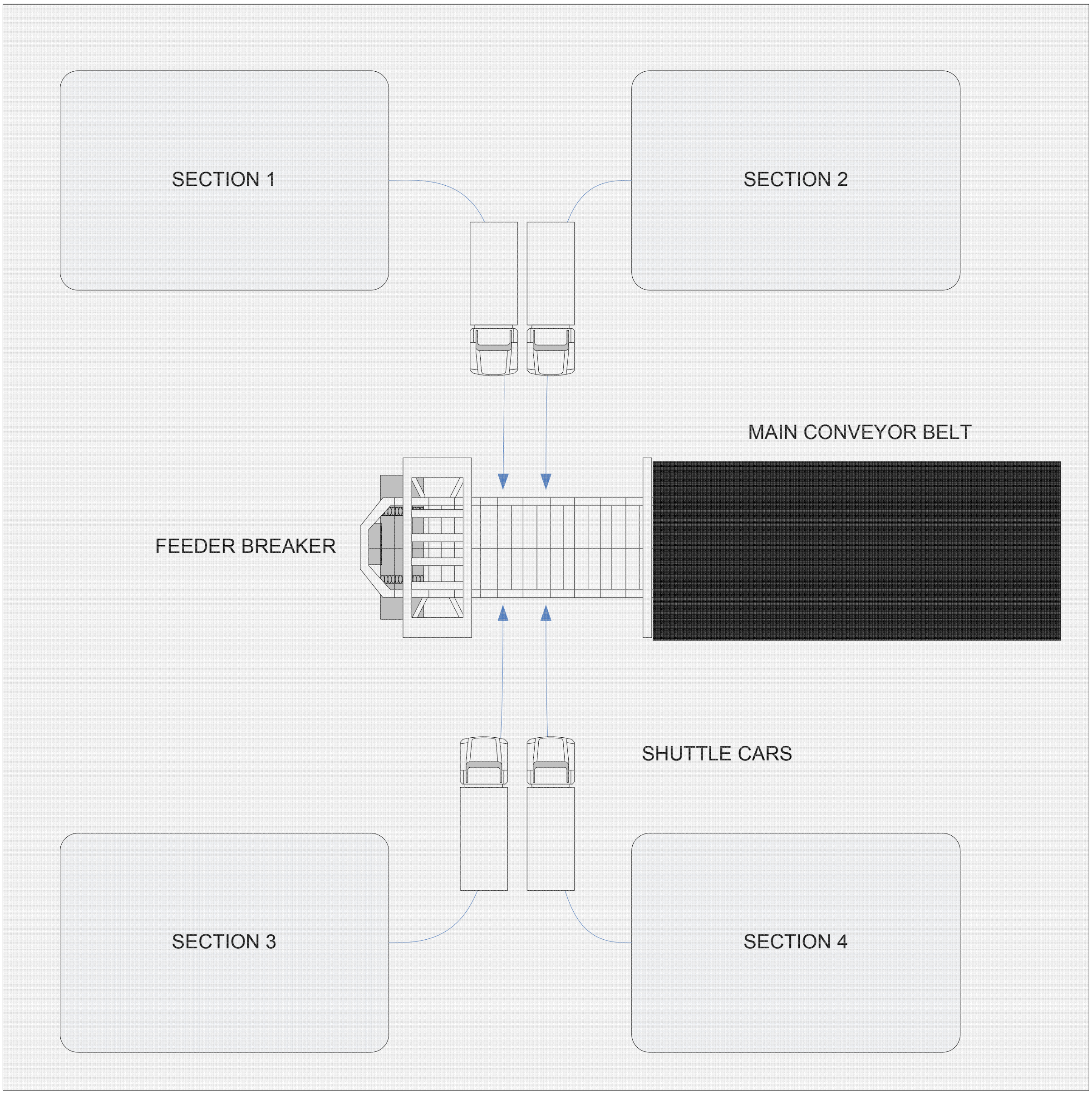
Sasol Limited is a power generation and fuel manufacturing undertaking. The undertaking was founded in 1979 to hold the assets of the South African Coal, Oil and Gas Corporation (Sasol). It has been involved globally in chemicals and fuels, employing around 30 000 people in 50 countries. Its main product, for years, was synthetic fuel recently Sasol is focusing primarily on its petrochemical business, as well as on efforts to convert natural gas into crude oil. One its most successful division is Sasol Mining.

1.2.2 Sigma Colliery

Sasol has an underground resources extraction division, Sasol Mining. Sigma Colliery is a coal mine under Sasol Mining, situated in Sasolburg. This coal mine opened its first shaft in 1957. It is currently extracting coal from a new shaft, Mooikraal. The Mooikraal shaft has four different sections.

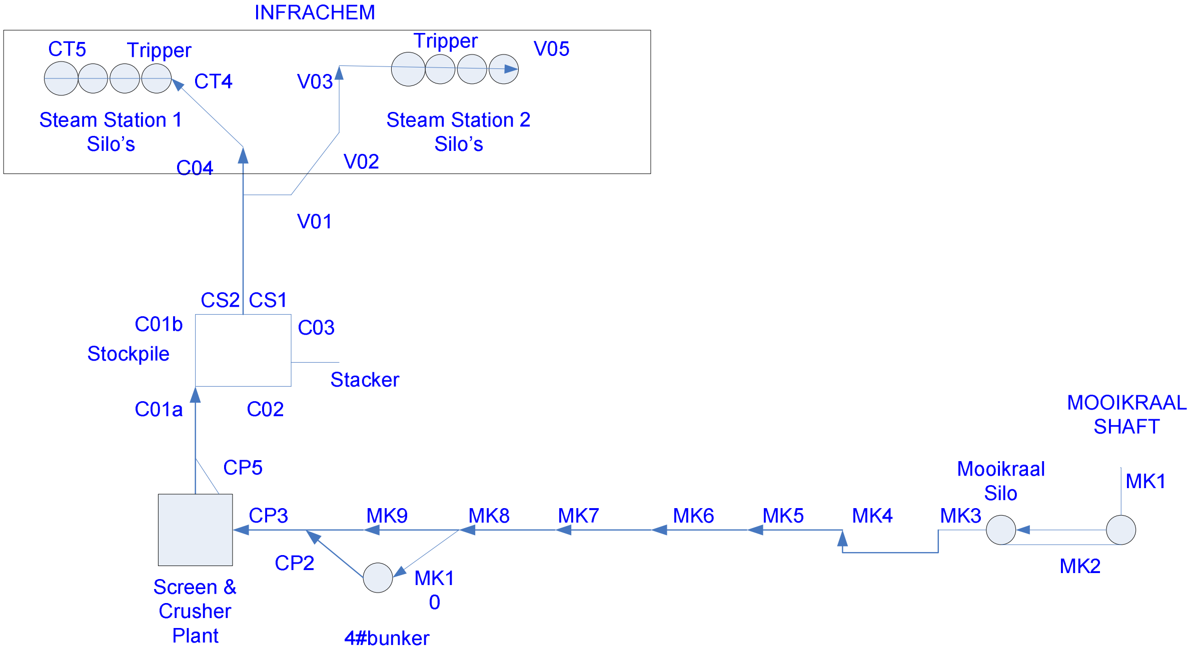
The different sections use shuttle cars to transport coal to the central point known as the feeder breaker, which feeds the coal to the main conveyor belt. Coal is conveyed all the way from underground to the blending station through the main conveyor belt as shown in Figure 1.1.

Figure 1.1: Mooikraal Shaft Underground Process



Coal is prepared before further transportation to customers (Infrachem) 22.56km from the shaft, as depicted by Figure 1.2.

Figure 1.2: Aerial View of the Sigma Colliery Conveyor Belt



The conveyor belt fills up large cylindrical storages 230m from the feeder breaker known as silos, first. This is done to draw coal from it if there should be a breakdown underground, or to offload coal just mined if there is a belt malfunction. The belt also goes through a bunker which is 19.4 km away from the silos. A bunker is a form of a shoot which stores coal and release it constantly to the conveyor belt before processing.

Evenly distributed coal from the bunker goes to the screen and crusher station, where it is crushed to sizes specified by the customer. The crushed coals are screened through a grid, only allowing coals within the specified size to pass the rest are re-crushed and re-screened.

The correctly sized coals are conveyed to the customer, Infrachem, only if their ash content is within the customer's specification. If, however, they are outside the specified boundaries they are offloaded at the stockpile through the stacker. Offloaded coal will have to be blended with other coal to be within the limits. When they have been blended to the allowable ash content range they will be conveyed through the C03 belt to the customer's steam stations 1 and 2 (Infrachem). The various conveyor belts with their length, width, power, speed, capacity and return idler are tabulated in Appendix A.

1.2.3 Infrachem

Infrachem is a steam generation plant equipped with two steam stations, see Figure 1. It falls under the power generation division of Sasol Limited. It produces electricity, de-mineralized water, and steam used in the production processes of several internal customers, including Sasol's plants producing diesel and petroleum fuel from coals. The Infrachem plant receives coal from Sigma Colliery. The coals are conveyed from the shaft to the site through belts. Infrachem is the one point in the chain that suffers the most impact from the boiler outage problem.

1.3 Objectives

The main objectives of this report are:

- To study the phenomena of coal formation in detail. Coal formation process, coal material composition as well as ash content determination.
- To design the production site layout, for the purpose of modification and integration of new equipment.
- Investigation of boiler operations, failures, and proposed solutions.
- Do detailed study of available technologies to counter the ash content determination problem.
- Formulation and development of conceptual designs.
- Develop the design implementation plans and strategies.

1.4 Project Aim

The aim of the project is to formulate and develop a holistic system that better blends the high ash content (above the specifications), with the low ash content to achieve constant ash content percentages that are within the upper and lower limit as per customer's specification.

1.5 Project Scope

The scope of the project covers the deliverables outlined in the document.

- **Coal blending model**- An accurate coal blending model will be formulated with constraints and will form the basis for the coal blending program. This will be a mathematical model defining the problem constraints and catering for any limitations and specifications.

- **Effective sampling method**- Develop an effective sampling method that overcomes the inaccuracy and time redundancy of the current sampling methods. This will cover all human resources aspects required, detailed operational steps, equipment needed as well as the technology.

- **Coal blending program/graphic user interface**- Design software operated program with a friendly graphic user interface for rapid blending amount determination and record keeping.

- **Coal blending station layout**- Design a coal blending station that will optimize the coal blending process while minimizing material handling and cost. This will include the physical layout and proposed equipment.

- **Machinery and technology acquisition**- the necessary machinery and technology required to optimize the different sections of the chain. Identify, evaluate and determine machinery and technologies that catalyses the efficiency of the process as a whole from underground coal extraction until steam generation.

- **Cost analysis**- Analyze the cost implications of the recommended modification of the current system, and perform a study to evaluate if such modifications are justified.

1.6 Conclusion

Chapter 1 discusses Sasol Mining's background in detail and gives a brief description of the underground activities. The objectives and project aim to be achieved under the outlined project scope are also stated. The rapidly increasing need for electricity and its priority transformation from being a luxury to being an absolute essential in our daily lives are the key factors motivating the importance of this project.

1.7 Document Structure

This report is a logical analysis of the background of the environment studied, current processes, and coal formation process; all necessary for the explicit understanding of the problem statement. The second part of this report is an extensive literature survey on boiler operation, coal blending methods, and ash content determination methods and techniques.

In the third part of this report, conceptual designs for remedial measures for improved boiler operations, coal blending methods, and process redesign are investigated. This is followed by the implementation plan for the various concepts, and a conclusion summarizing the advantages of the project.

2 Literature Study

2.1 Coal Formation

2.1.1 Introduction

Coal falls under the fossil fuel classification. It is the most used source of energy for the generation of electricity. It is, regrettably; also one of the largest sources of carbon dioxide emissions. According to Wesche (1991) coal is formed from plant remains that were protected by water and mud against oxidization and biodegradation, through trapping atmospheric carbon in the ground. Over a period of 300 to 400 million of years of compression, fossilized plant matter forms various stages of hard brown or black substance. As the black substance ages the water content decreases as the carbon content increases.

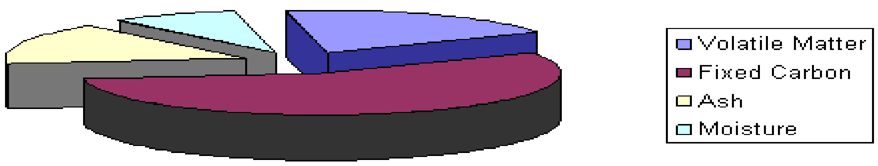
2.1.2 Coal composition

According to R.Kurose (2006) coal at all stages contains:

- Moisture – and water still remaining in the fossil fuel.
- Volatile matter-gases released when coal is heated.
- Fixed carbon - solid fuel left after the volatile matter is driven off.
- Ash - is non-combustable material which lowers the heating value and also presents problems for its disposal after burning. It can also cause corrosion and abrasion of boilers and clinkering or of furnaces. The ash content of coal is usually formed by clay minerals, carbonates (calcite, dolomite, and siderite), sulphides (pyrite, sphalerite, and galena) and silicates (quartz). Low ash content is desirable.

Figure 2.1 shows the graphical breakdown of a typical coal material composition (R.Kurose, 2006).

Figure 2.1: Typical Material Composition of Coal



The percentage of ash content in coal is of utmost importance as ash impedes the burning capability of coal and the heating values that can be achieved.

2.2 Boiler Operation

2.2.1 Introduction

It is important to be familiar with the operation of a boiler and all its components before one can investigate measures to control ash related failures. It is also important to know each important part of the boiler so that one can better understand research do by others. Most of the information in this section was adapted from Singer (1981).

2.2.2 Boiler Operation in a Nutshell

Boilers burn pulverized coal to generate heat. This heat is transferred to the walls of the boiler through radiation. The walls of the boiler consist of many vertical tubes through which water circulates. The heat it receives via radiation heats the water in the tubes and the water starts boiling. The steam and the water in the tubes are separated in the steam drum (Raask, 1985).

2.2.3 Boiler Components

- ***The Furnace***

Heat generated in the combustion process appears as furnace radiation. Water circulating through tubes that form the furnace wall lining absorbs a certain percentage of the heat. The water that boiled and turned into steam is absorbed whilst the remaining water will be re-heated with the incoming water feed (Raask, 1985).

- ***Superheater Tubes***

The purpose of the superheater is to raise the boiler steam temperature above the saturated temperature level. Superheaters designed for high temperatures and pressures require high-strength alloy tubing (Raask, 1985).

- ***Coal Crusher***

The purpose of a coal crusher is to grind coal to powder granules of the specified size. Coal is loaded into the crusher through the coal hopper. The coal is crushed into powder to allow for easy combustion in the furnace (Raask, 1985).

- ***Ash Disposal***

Burnt ash powder will be deposited in the ash hopper. Smoke (containing ash) will bet out through the exhaust pipe, passing through the precipitator pipe. The precipitator filters the smoke of ash before release it out into the atmosphere (Raask, 1985).

- ***Fuel-Burning Systems***

The ideal fuel burning system would have of the following characteristics:

- There must not be in excess oxygen or unburned fuel after combustion.
- Low energy input necessary for ignition.
- Stable combustion over a wide range of conditions.

High ash content coal inhibits the above mentioned statements. Figure 2.2 shows a pulverized boiler diagram and Figure 2.3 gives a comprehensive illustration of a boiler's operation.

Figure 2.2: Pulverized Boiler Diagram

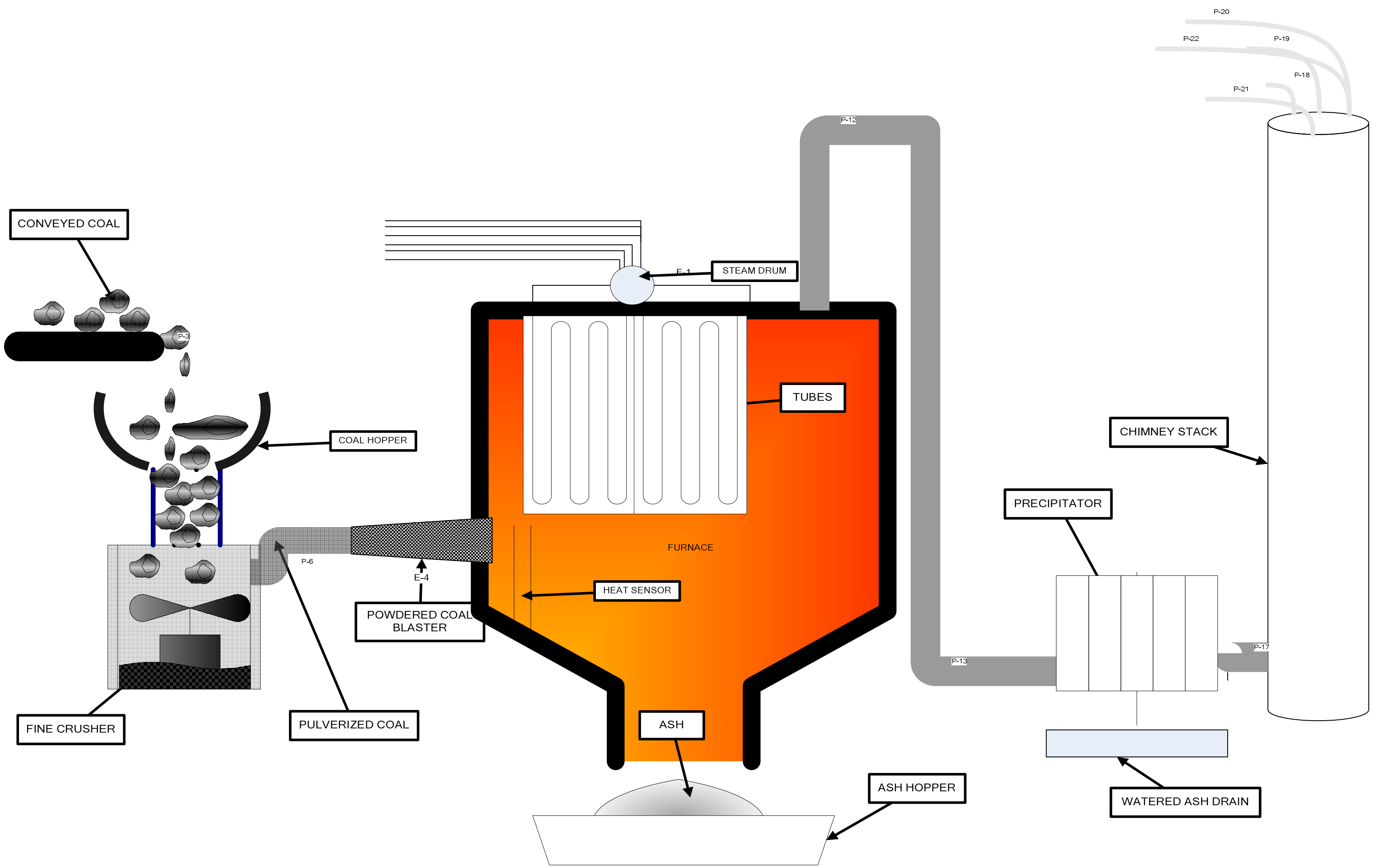
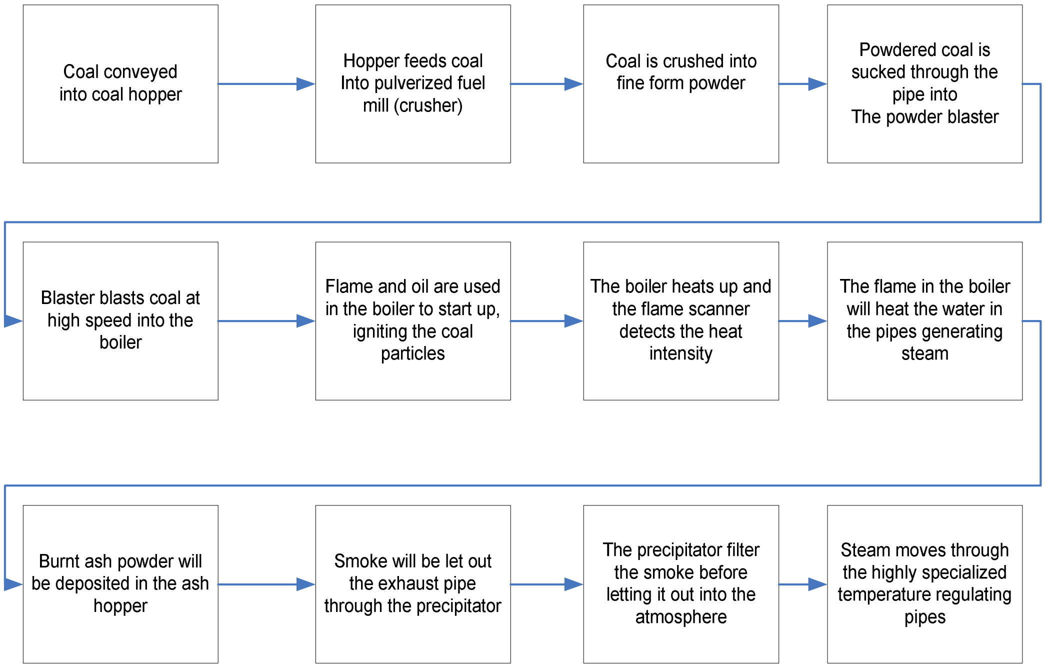


Figure 2.3: Boiler's Operation Process



2.3 Ash Related Failures

2.3.1 Introduction

Boiler failures constitute the major cause of lost availability in steam generating plants world-wide (Raask, 1985). There is plenty of published research on boiler failures and on the philosophy of how to prevent these failures. The bulk of this research covers a wide variety of failures and their respective causes. For the purpose of this report we will concentrate only on the ash related failures.

2.3.2 Failures in the Boiler Tubes

Low grade, ash-rich coals are frequently offered at attractive prices in the market. It is important to note that an increase in the average ash content could significantly increase the rate of erosion wear. Usually the higher the ash content of coal, the higher the quartz content of ash. It is thus possible that a 25 percent increase in the ash of coal may double the erosion wear propensity of ash (Jones, 1998).

2.3.3 Reasons for Ash Related Boiler Failures

As already discussed there are many reasons for boiler failures, to prevent deviation from the scope of this project only ash related failures will be discussed. Jones (1998) gives four major reasons for boiler failures:

- Tube overheating – improper determination of the ash content makes it difficult to determine the temperature at which the coal will burn.
- Tubes that have been attacked chemically – chemicals used to remove ash deposits damage the boiler walls.
- Tubes that are thinned down from the firewalls – ash deposits continually reheat the firewall, thus thinning the walls over a period of time.
- Boiler underperformance – high ash content impedes the burning capability of boilers, causing low temperatures that lead to boiler trips.

2.3.4 Ash Disposal Problems

Ash disposal is a major problem in coal utilizing industries. Table 1 explains the simplified Figure 2.4, showing only the different points that are problematic in the disposal of ash.

Figure 2.4: Ash Disposal Components of a Boiler

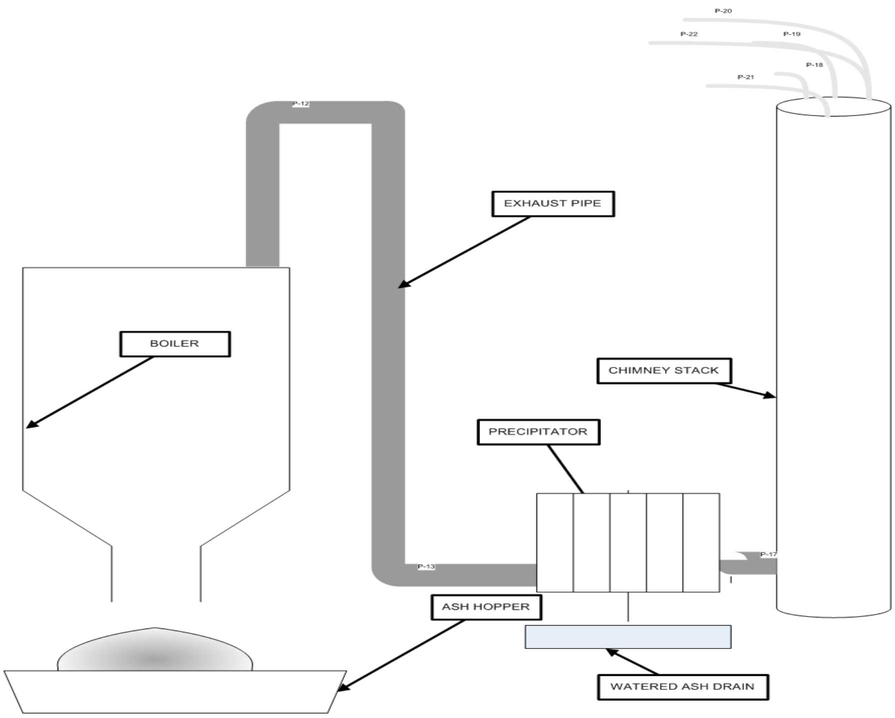


Table 1: Ash Disposal Problems.

Component Definition	Disposal problem
An Ash Hopper is generally a large tray that collects fly ash remaining after pulverized coal is burnt in the boiler.	Ash hopper is emptied at set intervals; if more ash is collected it may overflow.
An Exhaust Pipe is a cylindrical tube that serves as an exit for smoke in the boiler.	High ash coal leaves ash trapped in the smoke clogging up the pipe.
A Precipitator is a component that filters the smoke for any traces of ash	High ash contents in the smoke block the filter.
An Ash Drain is a disposal system for the watered before releasing it to the atmosphere.	A high amount of ash thickens the slurry, clogging the drain.

2.4 Sampling Methods

2.4.1 Introduction

Scheuren (2005) defines sampling as that part of statistical practice concerned with the selection of individual observations intended to yield some knowledge about a population of concern. In the mining industry, samples are also taken to have an indication of the coal's ash content.

2.4.2 Conventional Sampling Methods

In this method a small portion of the coal is taken and crushed into fine powder to burn quickly in the sampling furnace. It should be noted that the sampling process itself consumes the coal, thus for economic reasons small amounts are used for sampling purposes.

The coal is then loaded into a container that can withstand high temperatures. The weight of the coal is measured before and after the furnace. It is then assumed that after burning in the furnace all the other material components of the coal are burnt except the ash (incombustible).

In most mining undertakings conventional sampling methods use the basic proportion formula. The formula compares the weight of the material of interest to the total mass of its parent material (Raask, 1985). Since samples are placed in containers for furnace burning, the weight of the container is accountant for. This method is mathematical described in Equation (1) below.

x ***= container's weight***

y_a ***= weight of sample after furnace***

y_b ***= weight of sample before furnace***

% ash content = $[\, y_a - x\ (100)] / [\, y_b - x\,]$ ………………………………………….… (1)

2.4.3 Sampling Errors in Conventional Methods

This is an error rich form of sampling. Many of the sampling error stipulations according to Scheuren (2005) are present. Negligence of the laws of statistics is the major factor in the inaccurate results produced by this method. The causes for the high degree of error can be classified into two categories:

- ***Incorrect Assumptions***

Throughout the conventional methods of sampling the following incorrect assumptions are made swaying the results more to the irrational side of the outcomes:

- The ash is evenly distributed throughout the bulk being sampled.
- The material remaining after burning in the furnace is completely free of ash.
- The sample size is an insignificant factor considering the entire bulk being sampled (population).
- The weight of the container does not change due to heat.
- The deposits from the previous sample on the container do not affect the readings on the scale (container are re-used).

- ***Statistical sampling error.***

Scheuren (2005), states that an estimate of a quantity of interest, such as an average or percentage, will generally be subject to sample-to-sample variation. These variations in the possible sample values of a statistic can theoretically be expressed as sampling errors.

The likely size of the sampling error can generally be controlled by taking a large enough random sample from the population, although the cost of doing this may be prohibitive. Typically a larger sample size leads to increased precision in estimates of various properties of the population. In this method, as described above small samples sizes are taken compared to the entire population, and a small number of iteration is performed.

2.5 Ash Content Scanners

2.5.1 Introduction

Research done on conventional sampling methods and its flaws led, to more research into the new technology dependent measures of determining the ash content. There is different technology catering for specific needs of different plants.

2.5.2 Description and Principle of Operation

At the project site there are two instances where information about the coal ash content is needed. The same inaccurate method (conventional) of determining the ash content is currently used for both instances. These instances are:

- Determining the ash content of moving coals (conveyor belt).
- Determining the ash content of stationery coal (piled coal).

As mentioned before, for the purpose of this project it will be useful to collect and evaluate data of solutions to both instances. The ash monitor and the ash probe used to scan conveyed ash and piled ash respectively will be discussed below.

2.5.3 Ash Monitor

The ash monitor is a non-contacting instrument, which provides an on-line (conveyed) measure of the ash content of conveyed coal. It is based upon the original Natural Gamma Coal Quality Monitor (NGCQM). Produced by Bretby Gammatech Pty (LTD), the instrument relies on the fact that coals contain a much lower concentration of naturally occurring radioactive isotopes than the surrounding shale and mudstones.

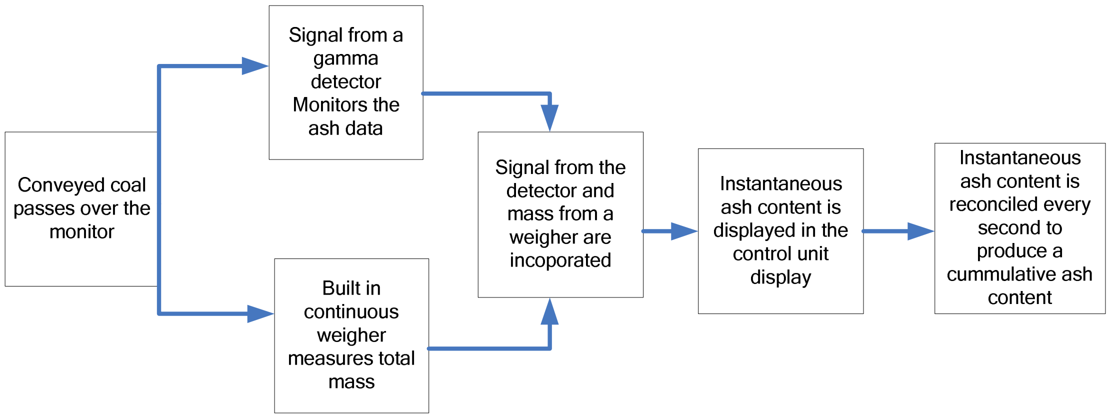
The level of gamma radiation emitted from a given weight of mined material increases with ash content.

The instrument calculates the ash content from the simultaneous measurement of the natural gamma radiation emitted by the conveyed material, and the weight of that material. Unlike many other monitors, it does not contain any radioactive sources. Given the increasingly widespread requirement to reduce the use of radioactive sources, this feature makes this instrument highly attractive. This instrument is mounted over the conveyor belt as shown in Figure 2.5.

Figure 2.5: Photograph of the Ash monitor installed in site

The simplified flow chart in Figure 2.6 describes the technical principle of operation.

Figure 2.6: Ash monitor's Principle of Operation



2.5.4 Ash Probe

In early 1997 customers identified the need for a portable instrument capable of providing a quick measure of the ash content of small piles of coal. After initial investigation such a system was designed, based upon natural gamma

Figure 2.7 and Figure 2.8, shows the ash probe comprising of the probe and display unit and the ash probe in use, respectively. Up to 18 probing per pile can be stored and the average ash content displayed. There is also provision for the recording of up to 18 piles of ash data along with the ability to use up to nine different calibrations. The data can later be downloaded to a computer.

Figure 2.7: The Ash Probe and the Display Unit

Figure 2.8: The Ash Probe in Use

2.5.5 Reliability Experiment Results

As attractive as most of the technological inventions and innovations are, not all of are accurate or reliable in delivering results. Thus, when dealing with unpopular technology it is best to check the reliability of the system

The ash scanners have high levels of accuracy, and it is highly recommend. In a series of experiments to analyse their reliability they excelled.

Table 2 below shows the results of the scanners compared to practically analysed ash contents of the samples.

Table 2: Ash probe calibration results

Sample no.	Sample Name	Analysed Ash (%)	Ash Probe Ash (%)	Difference Ash (%)
1	Blend 1	15.7	16.8	1.1
2	Blend 2	13.1	14.6	1.5
3	Blend 3	14.6	13.0	-1.6
4	Blend 4	20.1	20.7	0.6
5	Blend 5	30.2	31.5	1.3
6	Blend 6	28.0	24.8	-3.2

The tabulated results show that the gamma technology is acceptably reliable is monitoring the ash content in coal.

2.6 Conclusion

Chapter 3 forms the comprehensive literature study necessary for the execution of the project. The coal formation process, boiler operation and its ash related failures, sampling methods and ash content scanners were necessary to study in order to better understand the problem and formulate effective remedial measures.

The knowledge from the literature study will be used in conjunction with learned Industrial Engineering methods, tools, and techniques to formulate, evaluate and develop concepts.

3 Conceptual Designs Development

3.1 Introduction

The literature study equips us with knowledge that can be used collaboratively with Industrial Engineering methods, tools and techniques to effectively conceptualize on effective designs to solve the problem. Different components of the design will be discussed in detail independently and their incorporation into one holistic system complementing each other in the design.

3.2 Machinery

The project environment and site is too complex to be modified to function both effectively and economically without employing supplementary technology. The equipment discussed in the literature review will be employed in the design.

3.2.1 Ash Monitor

The ash monitor will be installed along the conveyor belt to accurately determine the instantaneous and cumulative ash content, in percentages, of the conveyed coal. For ample time to prepare for the blending process, if required, the monitor should be installed as close as possible from the starting end of the conveyor belt.

The ash monitor if favorably installed, systematically, will yield the following advantages to the system:

- Accurate ash content measurements.
- Prompt ash content determination.
- Economic blending process.
- Blending station organization.

The above advantages are all paramount for achieving the objectives of the project, thus justifying the ash monitor's requirement as part of the design.

3.2.2 Ash Probe

The stockpile, defined as the storage of blending coal, also requires means to determine the ash content of its stationery coal. Acquisition of a single ash probe for this purpose will simplify the process greatly contributing the following vital advantages:

- Different piles ash content measurements.
- More accurate results than conventional methods.
- Stockpile categorisation/separation tool.
- Pre-pulverization (crushing) sampling tool.

3.3 Coal Blending Station layout Design

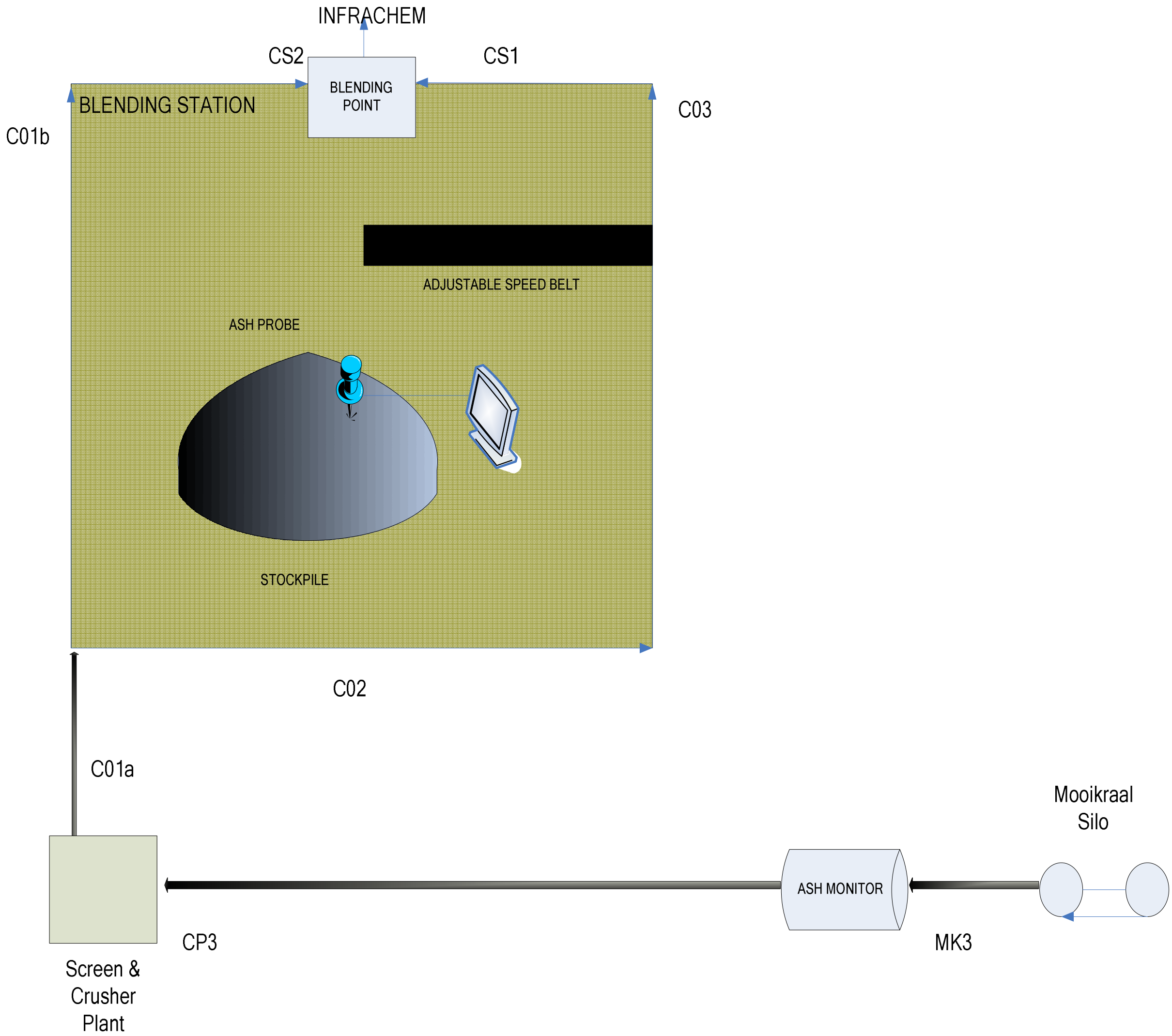
The positive efficiency impact caused by the machinery to be acquired depends greatly on the layout of the entire system. It is consequently important to determine the exact positioning of the ash monitor for its optimal operation, and a layout that complements the use of the ash probe.

The ash monitor is fitted at the end of the MK3 conveyor belt 20.6 km away from the blending station. This positioning gives operators at the blending station 108 to 163miutes, depending on the varying speeds of different belts, to prepare the suitable blending.

The ash probe will be used in the stockpile to determine the ash content of the coal kept at the stockpile. Using the data sent by the ash monitor operators will manipulate the C01a, C01b and C02 conveyor belts to either direct the coal to the blending station or to Infrachem.

Figure 3.1 shows the proposed facility layout and the positioning of the ash monitor and ash probe. Instantaneous and cumulative ash content results detected by the ash monitor will be sent to the operator, who in turn uses the ash probe to prepare a complimentary blend from the stockpile if needed.

Figure 3.1: Coal Blending System Facility Layout



3.3.1 Blending station

The blending stations organization is shown in Figure 3.2. The different components and tools of the station are defined below:

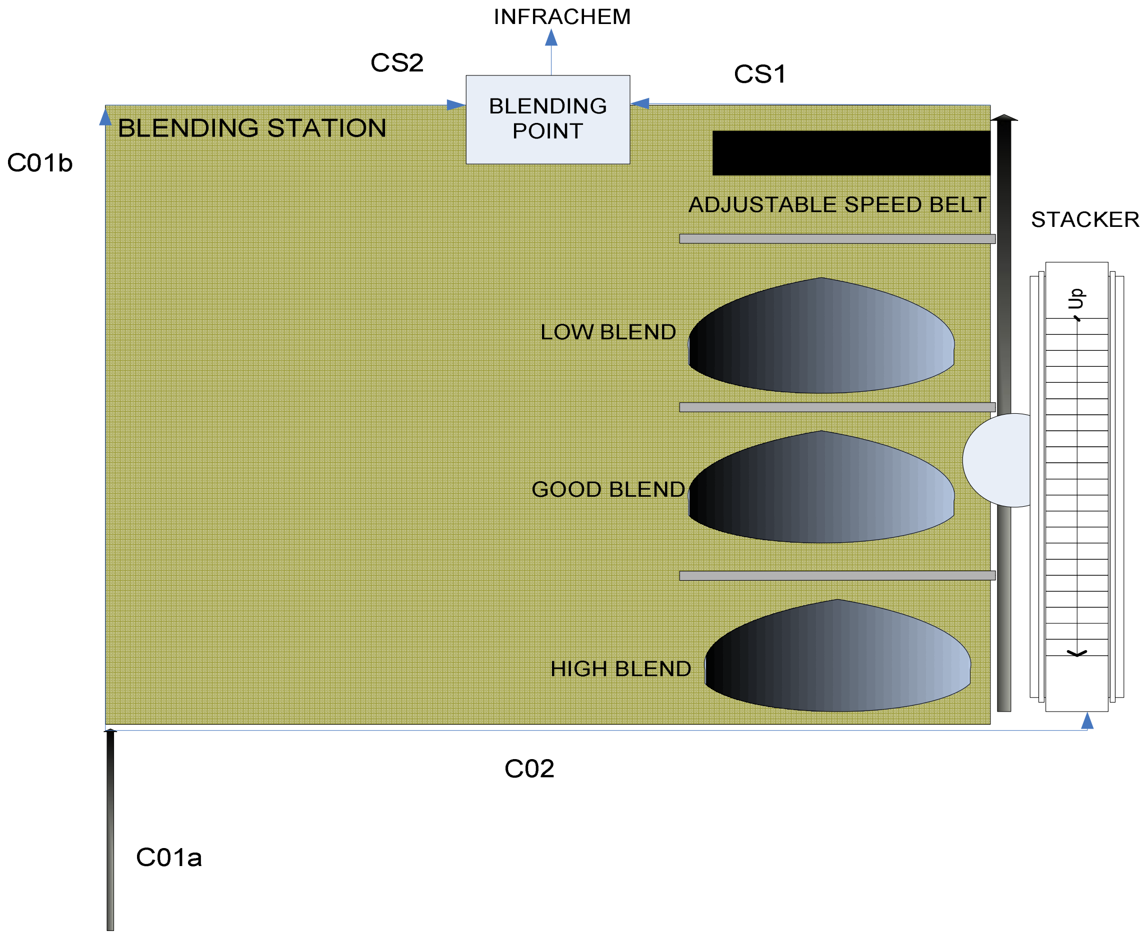
High blend - coal with an ash content exceeding the customer's specifications. (Greater than 31.5 %)

Good blend – coal with an ash content within the customer's specifications. (Between 30.5% and 31.5%)

Low blend – coal with an ash content below the customer's specification. (Less than 30.5%)

Stacker – Mobile extension belt that can be positioned directly at the point where it should offload coal.

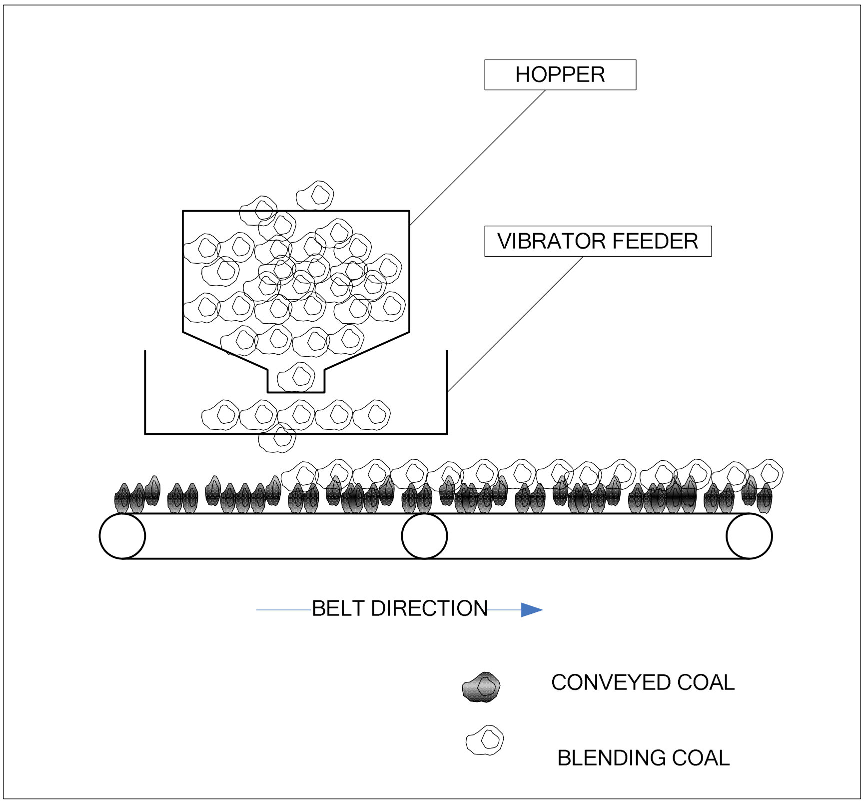
Figure 3.2: Detailed View of the Blending Station



3.3.2 Blending Point

Depending on the ash content of the conveyed coal on the CS2 belt the complementary blending coal from the blending station is loaded onto the adjustable belt. The blending coal is poured into the hopper through the CS1 belt. Hopper loads the coal into a vibrator feeder which ensures even distribution of the blending coal throughout the belt. This takes place at the blend point as illustrated by Figure 3.3 below.

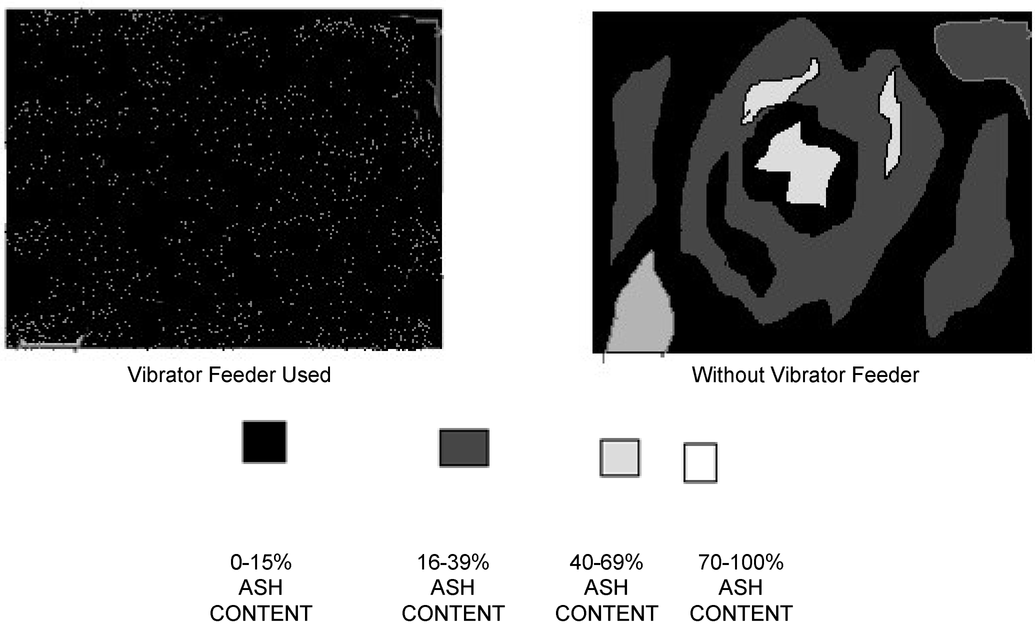
Figure 3.3: Magnified View of the Blending Point



It is important to note the importance of properly mixing the two blends at blending point. For this purpose, a vibrator feeder is used. Exclusion of the feeder means heaps of the different blend will be stacked on each other on the belt. This inconsistency in the mixing can defeat the purpose of the whole project.

Carbon image scanners take pictures of carbon (coal) and ash on the conveyor belt. Carbon appears darker than ash. Figure 3.4 shows the difference in blend distribution and proper mixing of the blends using a vibrator feeder, as compared to its exclusion at the blending point.

Figure 3.4: Carbon Image Scanner with and without a Vibrator Feeder.



3.4 Blending Model

Despite the application of the technology discussed above and facility layout redesign, the system still lacks an accurate and precise model that will guide the blending process. The model should clearly define how much coal (in tons) of what ash content (in % ash) should be blended with what to produce a mixture satisfying the prescribed customer specifications. The following model will serve the purpose.

Variables:

$x_{high} \triangleq$ the weight (in tons) of high ash coal (coal with an ash content >35%)

$x_{low} \triangleq$ the weight (in tons) of low ash coal (coal with an ash content <35%)

$y_{high} \triangleq$ ash content (in%) in x_{high}, high ash coal

$y_{low} \triangleq$ ash content (in%) in x_{low}, low ash coal

Objective function(s):

x_{high} $=\{(x_{low} * y_{low}) - (30.5 * x_{low})\}/(30.5 - x_{low})$……...........(2)

x_{low} $=\{(x_{high} * y_{high}) - (31.5 * x_{high})\}/(31.5 - y_{high})$…………(3)

Subject to:

[Total Weight Constraint]

$T_{weight} = \sum x_j \quad \forall \quad j \in \{ low;high \}$…..(4)

[Total Ash Content Constraint]

$T_{\%}$ = ash % in T_{weight}………………………….(5)

[Lower Limit Ash Content Constraint]

$\{(x_{high} * y_{high}) + (x_{low} * y_{low})\} / T_{weight} \geq 30.5$ ……………………………..……….(6)

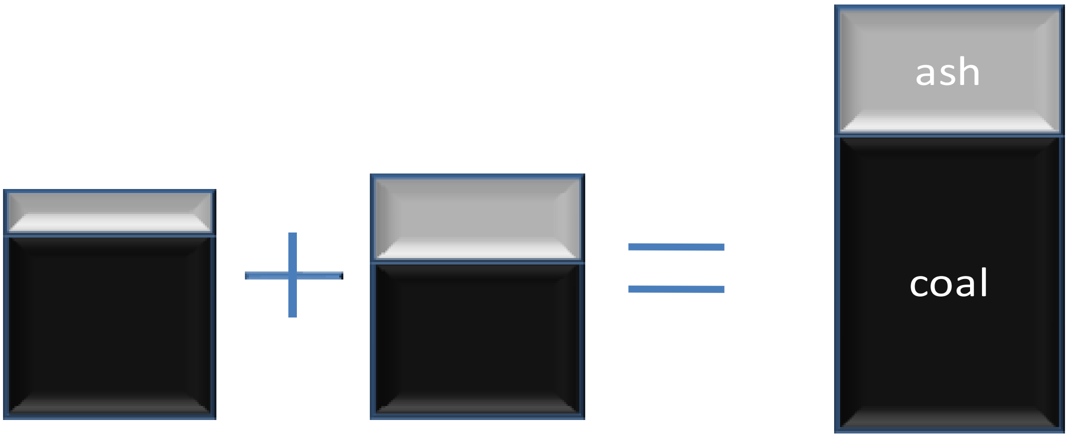
[Lower Limit Ash Content Constraint]

$\{(x_{high} * y_{high}) + (x_{low} * y_{low})\} / T_{weight} \leq 31.5$ ……………………………..……….(7)

3.4.1 Model Accuracy Verification

The blending model is based on the basic concentration equation. The model states, in words that if two common entities each with a certain concentration of a particular element, are added the concentration of their sum will be the sum of the elements over their total mass. This principle is figuratively described in Figure 3.5.

Figure 3.5: Concentration Principle



Several tests were conducted physically and their results compared to those generated by the model, the impeccable results in Table 3, verified the accuracy and precision of the model. Figure 3.6 compares the physically measured results against the model generated result.

Figure 3.6: Model Output and Measured Output Comparison

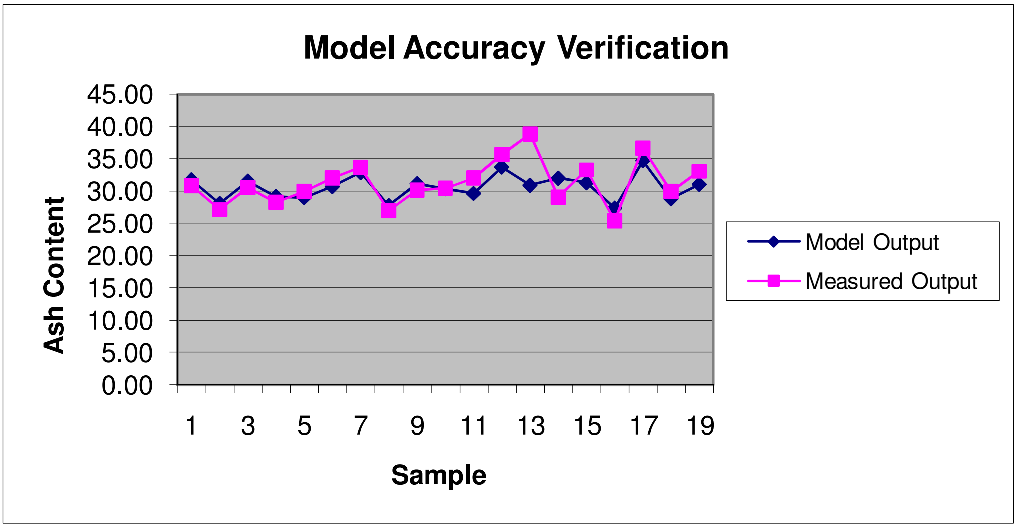


Table 3: Model Accuracy Verification Results

X high	X low	Y high	Y low	T weight	**T % Model Output**	**T % Measured Output**	Difference (%)
1.3	1	34.6	28	2.3	31.73	30.85	-2.85
1.5	2.3	40	20.3	3.8	28.08	27.1	-3.6
2	3.45	38	27.8	5.45	31.54	30.52	-3.35
1.79	3	38.56	23.56	4.79	29.17	28.23	-3.31
2.5	2.5	34.5	23.45	5	28.98	29.96	3.29
1.8	3	32.34	29.67	4.8	30.67	32.01	4.18
2	2	39	26.76	4	32.88	33.69	2.4
2.5	3	31.5	24.56	5.5	27.71	26.93	-2.91
0.5	1	33.33	30.01	1.5	31.12	30.16	-3.17
3	3.06	32	28.75	6.06	30.36	30.42	0.2
1.6	1.95	35.65	24.67	3.55	29.62	32.02	7.5
2.3	3	38.95	29.67	5.3	33.7	35.67	5.53
2.09	3.4	32.22	30.05	5.49	30.88	38.88	20.59
2.75	2.8	34.45	29.54	5.55	31.97	29.02	-10.18
2.34	2.67	35.06	28	5.01	31.3	33.27	5.93
1.8	2	32.11	23.05	3.8	27.34	25.36	-7.81
1.5	1.09	39.8	27.65	2.59	34.69	36.71	5.51
2.34	2.5	33.62	24.32	4.84	28.82	29.9	3.62
3	2.75	37.98	23.45	5.75	31.03	33.07	6.17

For the accuracy verification Equation (8a) and (8b) were used. These equations were derived from (4), (5), (6), and (7).

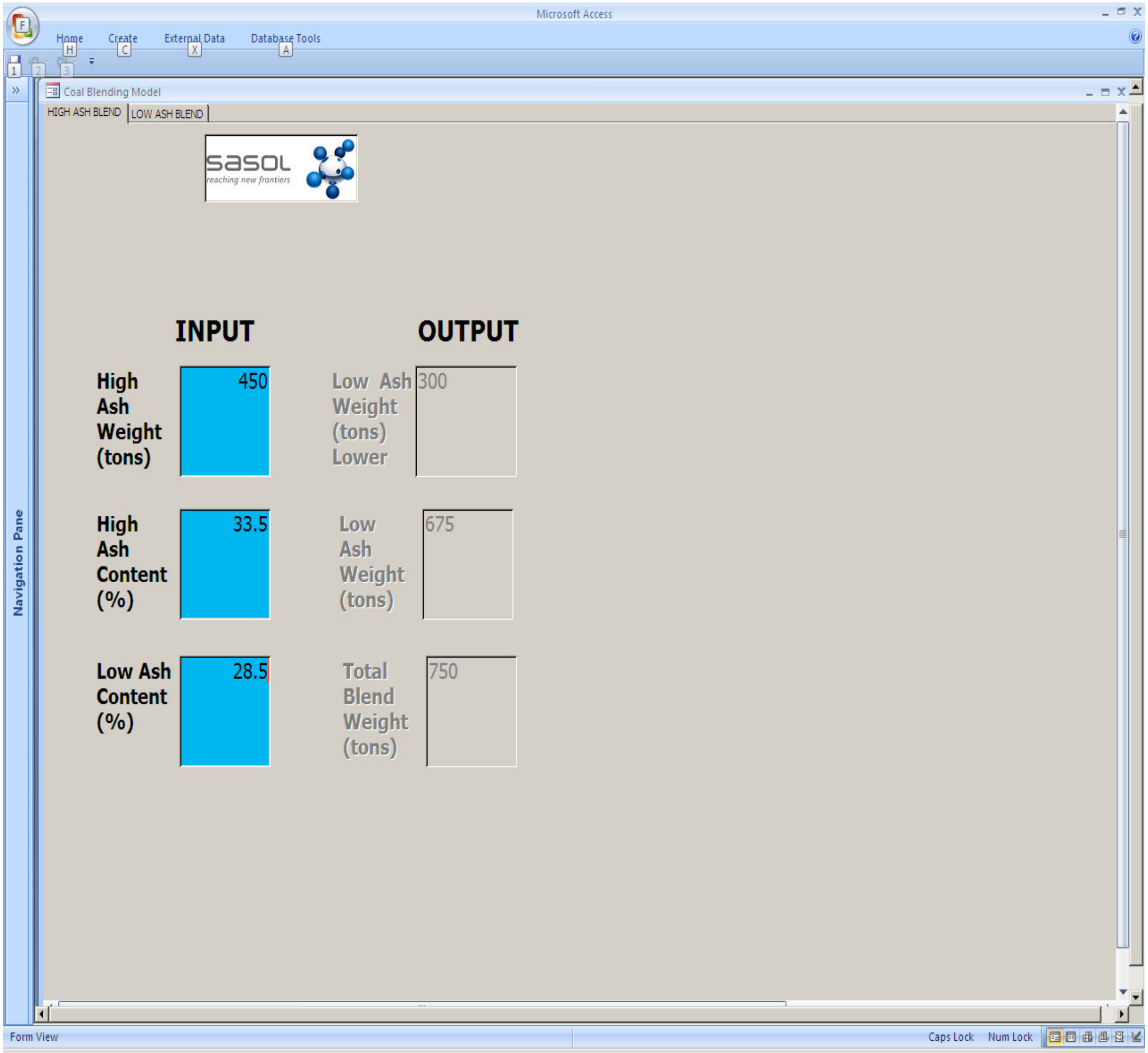
$$(x_{high} * y_{high}) + (x_{low} * y_{low}) = T_{weight} * T_{\%} \qquad \text{.......(8a)}$$

$$T_{\%} = \{(x_{high} * y_{high}) + (x_{low} * y_{low})\} / T_{weight} \qquad \text{.......(8b)}$$

3.5 Coal Blending Graphic User Interface (GUI)

The model developed in the previous section, although accurate, has a certain level of intricacy and require a relatively high level of mathematical literacy form the operator who will be performing iterations on it. Since coal blending executions are generally low level tasks with semi-skilled labourers executing the tasks, it may render useless if not understood. To prevent redundancy of the model due to its complexity, a simplified graphic user interface (GUI), shown in Figure 3.7, was designed.

Figure 3.7: Graphic User Interface



The GUI was programmed using the model to simply the use thereof. The operator, following the manual, only has to enter values and the GUI will run the model generating the output. It must be understood that although the GUI was created in MS Access, it is not a database. It may be viewed as a (programmed) calculator.

3.5.1 Graphic User Interface Instructional Manual.

The main window has two tab controls namely, the High Ash Blend and the Low Ash Blend. The two tab controls cater for the two fundamental problems, when there's known amount of high ash coal and the amount of low ash coal needs to be determined and vice versa.

- ***High Ash Blend Tab***

This is tab is used when high ash content coal (greater 31.5%) of known ash content needs blending to be within specifications, and the operator needs to know how much of the low ash coal (below 30.5%) to blend with and the total weight of resultant blend.

<u>Input Fields</u>: in these fields the operator can enter values into the GUI.

High Ash Weight - the amount of high ash coal, in tons, that needs blending.
High Ash Content - the ash content in %, in high ash coal that needs blending.
Low Ash Content – the ash content in %, in low ash coal used to blend.

<u>Output Field</u>: these fields are disabled; the user cannot enter or change the displayed values.

Low Ash Weight (Lower Limit) – the minimum amount of low ash coal, in tons, that can be used to blend.
Low Ash Weight (Upper Limit) – the maximum amount of low ash coal, in tons, that can be used to blend.
Total Blend Weight – the total weight of the within specification blend.

- ***Low Ash Blend Tab***

This is tab is used when low ash content coal (below 30.5%) of known ash content needs blending to be within specifications, and the operator needs to know how much of the high ash coal (greater than 31.5%) to blend with and the total weight of resultant blend.

Input Fields: in these fields the operator can enter values into the GUI.

Low Ash Weight - the amount of low ash coal, in tons, that needs blending.
Low Ash Content - the ash content in %, in low ash coal that needs blending.
High Ash Content – the ash content in %, in high ash coal used to blend.

Output Field: these fields are disabled; the user cannot enter or change the displayed values.

High Ash Weight (Lower Limit) – the minimum amount of high ash coal, in tons, that can be used to blend.
High Ash Weight (Upper Limit) – the maximum amount of high ash coal, in tons, that can be used to blend.
Total Blend Weight – the total weight of the within specification blend.

3.6 Conclusion.

The concepts developed in this chapter were subjected to intense scrutiny during the evaluation phase to determine their efficiency, effectiveness and proper operation. Each concept functions excellently and is dependent on the proper operations of other supplementary concepts; the interdependencies of these concepts will be demonstrated in the next chapter.

4 Implementation

4.1 Introduction

The coal blending process is a lengthy and considerably complex one. The concepts designed are all, in one way or another, aimed at shortening and simplifying it. This should be executed whilst increasing the attainability of the process objectives and its accuracy thereof. The implementation of the different concepts and their functionality within the entire system is paramount to term the project a success.

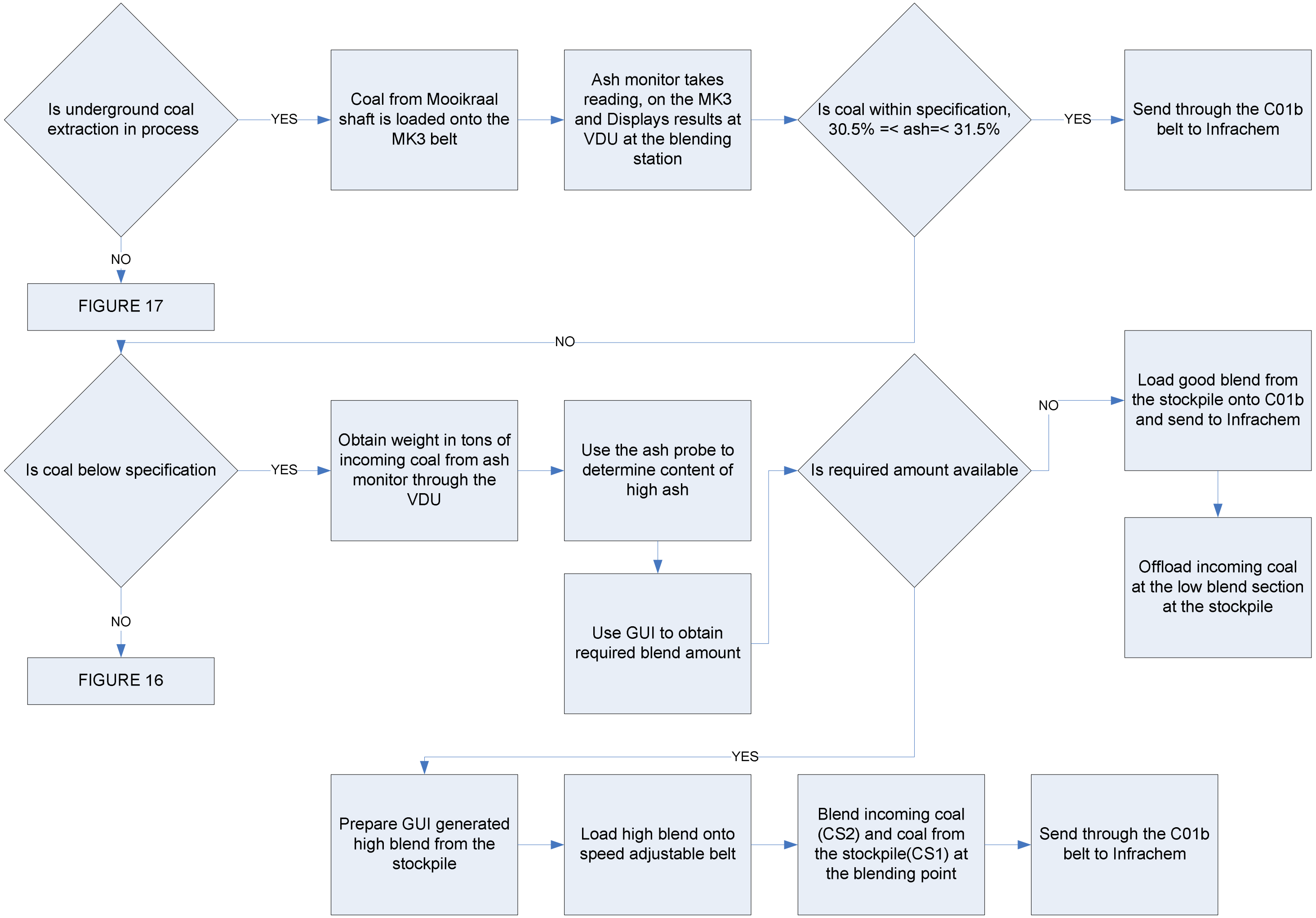
4.2 The Four Possible States of Coal Blending

In the coal blending environment there are typically four cases, depending on the coal extracted, that the process falls under. The implementation of the concepts will be such that every case is catered for thus improving the process in all angles. The four cases are discussed below.

4.2.1 Extracted Coal's Ash Content below Specifications

This happens when the ash monitor at the MK3 conveyor belt reports that the cumulative ash content of the conveyed coal is below 30.5%. Due to the rapid content determination of the monitor, this information is sent to the visual display unit (VDU) located at the blending station when the coal is over 2 hours away; giving the operators ample time to carry out the blending process. Figure 4.1 gives the implementation plan for this particular case.

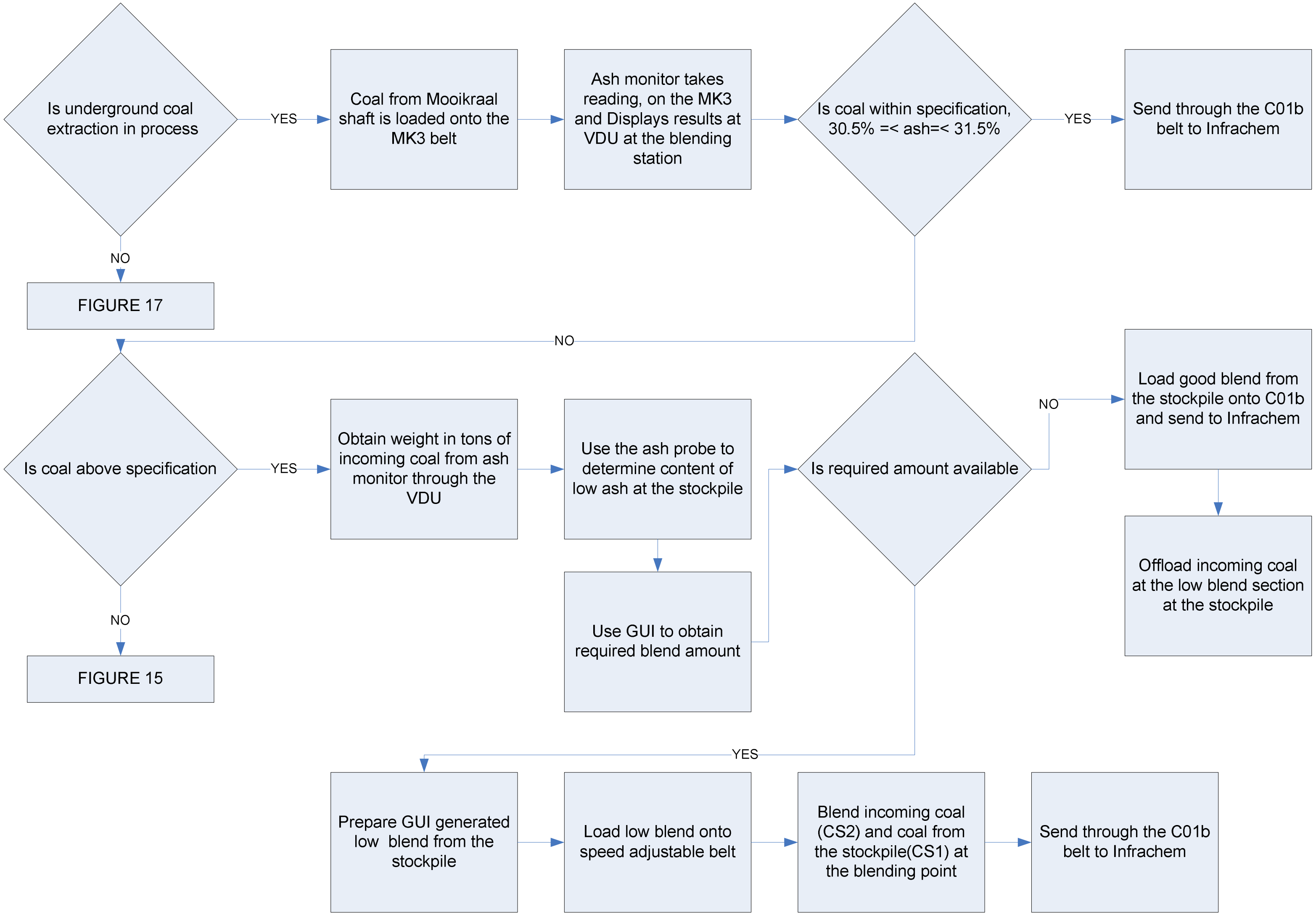
Figure 4.1: System Implementation – Content below Specifications



4.2.2 Extracted Coal's Ash Content above Specifications

If the ash monitor detects the cumulative ash content of extracted coal is greater than 31.5% at the MK3 conveyor belt, then the implementation plan show in Figure 4.2 will be followed. The main aim of the process is to reduce the ash content to a value less than 31.5% but also satisfy the lower limit of 30.5.

Figure 4.2: System Implementation – Content below Specifications



4.2.3 Production Downtime

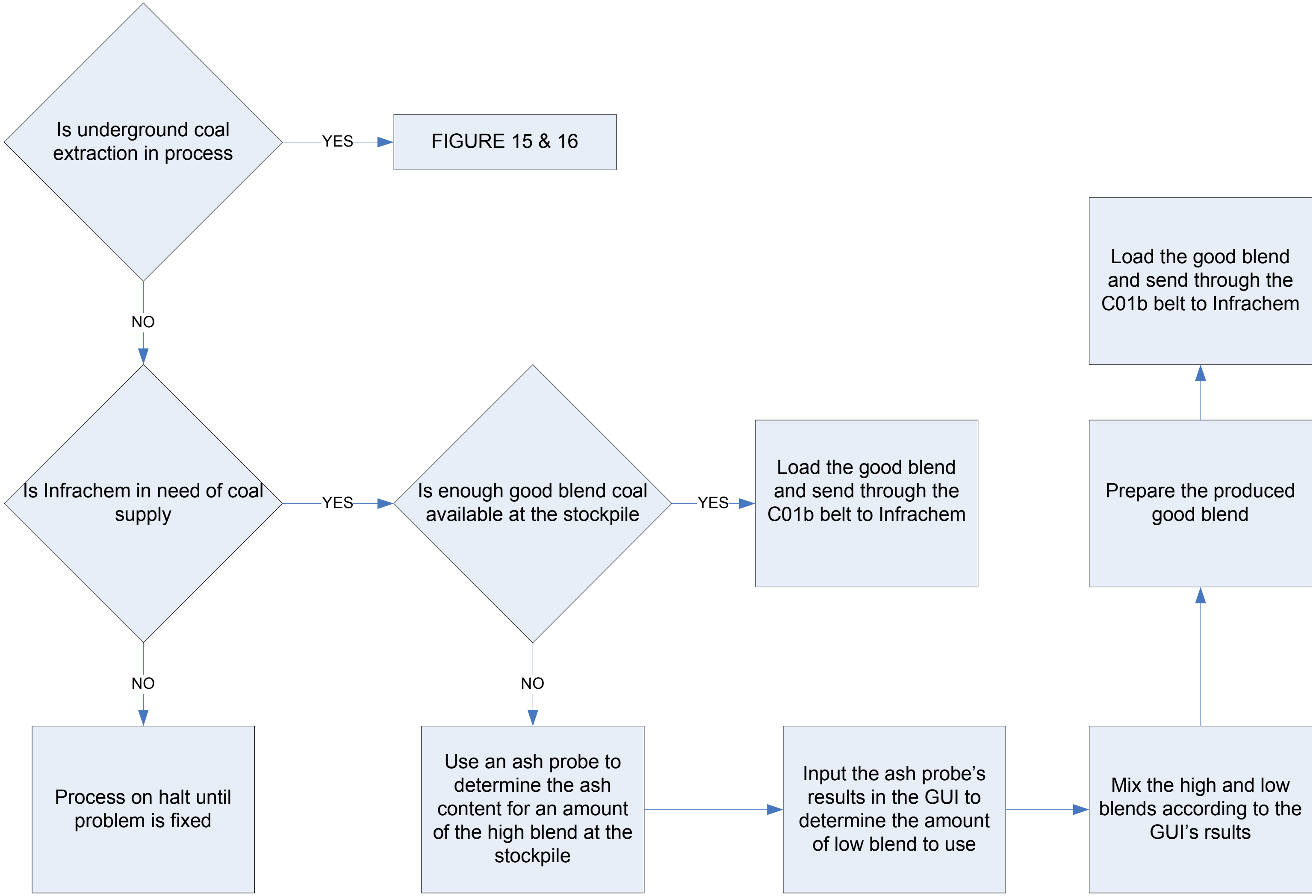
Production Downtime is a period of time during which a machine is not available for use because of maintenance or breakdown or, the amount of time lost due to forces beyond one's control, as with a computer crash, especially for a profit making enterprise. (Christer, 1984)

If the downtime is on the coal extraction and supply section, it is important to determine if the powerstation (Infrachem) needs a supply urgently, or they can carry out their operations without supply for the estimated duration of the downtime. Figure 4.3 gives the process followed during a downtime.

The following are the most common factors contributing to downtime:

- Conveyor belt tearing.
- Underground extraction machinery failure.
- Pit stops – short but regular periods when the line is stopped for inspection and repair.
- Planned maintenance – thorough servicing of machinery, along with any subsequent adjustments and repairs.

Figure 4.3: System Implementation – Production Downtime



4.2.4 Extracted Coal's Ash Content within Specifications

If the reported ash monitor's readings are between 30.5% and 31.5%, the coal conveyed is said to be within the specifications. In this instance there will be no interreference with the process the coal will be sent directly to Infrachem through the C01a, C01b, CS2 and C04 conveyor belt.

4.3 Change Management

Change management is a tool used for the smooth transition from the **as-is** to the **to-be** state. Change management will be used as an implementation strategy. In his article Aguire (2004) defines change management as the process of requesting, determining attainability, planning, implementing and evaluation of changes to a system. Change management can be seen as the facilitation of change in a way ensures the successful implementation and acceptance of change.

Change management can be broken up into three phases:

4.3.1 Innovation and Leadership Phase

In this phase the change or improvement is determined and a formal change leadership structure is set up. Proper leadership is important, lower level employees will need guidance. At Sigma Colliery the following people are recommended to be part of he leadership structure, considering their tasks will be directly affected by the change:

- Chief Belt Operator.
- Resources Manager.
- Blending Station Foreman.
- Plant surface manager.
- Powerstation Acquisition Clerk.
- Information Technology Specialist.

4.3.2 Implementation and Management Phase

During this phase, the changes and improvements deemed necessary during the previous phase implemented. During the implementation phase, proper management is needed to ensure a successful implementation process.

The mine's projects manager will analyse the functional capabilities of the process developed to cater for the four different states of coal blending.

4.3.3 Improvement Phase

During this phase any further improvements to systems are implemented. This is continuous process. Thus change management is very important and inevitable to ensure favourable results of system changes. Evaluation of the previous process at the mine and make improvement recommendations to any problematic areas.

4.4 Cost Analysis – Feasibility Study

A cost analysis will be done to determine how well, or how poorly, the planned implementation will turn out. This analysis is based on financial terms, determining how viable the concepts and their implementation are, financially.

The average number of boiler trips related to high ash content in the coal is 39 trips per year. The cost of boiler start up after a trip induced by high ash content is R5.000. Total cost of oil used to start up a boiler and extra cost for ash removal due to high ash content of coal is R8.000.00 per year. The cost, to Sigma Colliery, of acquiring the ash monitor and ash probe will be R5.000.000 and R90.000 respectively.

Sigma Colliery, through Sasol's capital process, will obtain a loan from Sasol Mining. The loan can be paid back through depreciation, over the devaluing period. The evaluation process of the feasibility of the project will be performed using After-Tax Economic Analysis. This method transforms before tax cash flow (BTCF) estimates into after tax cash flow (ATCF). This method considers the important effects of tax over the life of the project. (Blank and Tarquin, 2005). The (BTCF) and (ATCF) indicate the actual flow of money in and out of Sigma Colliery that will be yielded by the execution of the project.

The MARR is (Minimum Attractive Rate of Return). A Net Present Value (NPV) is representation of the monetory value of the entire project at a time deemed the present.

The analysis list the cash flow generated by the project, and then deducts depreciation of machinery, loan payments and their interest, and the tax incurred. The cash flows are then moved, considering the effects of time and rate of return, backwards throughout the project life into the present. The value generated is the Net Present Value (NPV). A positive net present value means the project is viable. Table 4 contains the data needed to successfully compute the NPV, and Table 5 shows the calculation of the ATCF cash flows after the effects of tax have been accounted for on the BTCF . The rest of the calculation is given below.

Table 4: Calculation Data.

Element	Value
Before tax MARR	10%
Effective tax rate	40%
Tax life	10 years
Project life	20 years
Residual value (t=10 years)	R450.000
Market value (t=20 years)	R600 000
Loan amount	R5.090.000
Interest payable on loan	15%
Loan payback period	5 years
Annual Savings	R8195000

After tax MARR = MARR (Before tax)*(1-Tax rate)

= 10%(1-0.4)

= 6%

Annual loan payment =R5.090.000(A/P, 15,5)

= R5.090.000(0.29832)

= R1.518.448

Annual Interest:

I_{y1} = R1.518.448(P/A,15,5)(0.15)

= R1.518.448(3.3522)(0.15)

= R763.521

I_{y2} = R1.518.448(P/A,15,4)(0.15)

= R1.518.448(2.8550) (0.15)

= R650.275

I_{y3} = R1.518.448(P/A,15,3)(0.15)

= R1.518.448(2.2832) (0.15)

= R520.038

I_{y4} = R1.518.448(P/A,15,2) (0.15)

= R1.518.448(1.6257) (0.15)

= R370.281

I_{y5} = R1.518.448(P/A,15,1) (0.15)

= R1.518.448(0.8696) (0.15)

= R198.066

Depreciation = (First Cost – Residual Value)/ Tax Life

= (5.090.000 – 450.000)/10

=R 464000

Table 5: transition from BTCF to ATCF

	A	B	C	D	E	F	G	H
					=A-B-D	E*40%		=A-F-G
Year	BTCF	Depreciation	Book Value	Interest	Taxable income	Tax	Loan	ATCF
0	-5090000							-5090000
1	8195000	464000	5090000	763521	6967479	2786992	1518448	3889560
2	8195000	464000	4626000	650275	7080725	2832290	1518448	3844262
3	8195000	464000	4162000	520038	7210962	2884385	1518448	3792167
4	8195000	464000	3698000	370281	7360719	2944288	1518448	3732264
5	8195000	464000	3234000	198066	7532934	3013174	1518448	3663378
6	8195000	464000	2770000		7731000	3092400		5102600
7	8195000	464000	2306000		7731000	3092400		5102600
8	8195000	464000	1842000		7731000	3092400		5102600
9	8195000	464000	1378000		7731000	3092400		5102600
10	8195000	464000	914000		7731000	3092400		5102600
11	8195000		450000		8195000	3278000		4917000
12	8195000				8195000	3278000		4917000
13	8195000				8195000	3278000		4917000
14	8195000				8195000	3278000		4917000
15	8195000				8195000	3278000		4917000
16	8195000				8195000	3278000		4917000
17	8195000				8195000	3278000		4917000
18	8195000				8195000	3278000		4917000
19	8195000				8195000	3278000		4917000
20	8195000				8195000	3278000		4917000
MV	600000		450000		150000	60000		540000

NPV= -5090000+3889560(P/F,6,1)+3844262(P/F,6,2)+3792167(P/F,6,3)
+3732264(P/F,6,4)+3663378(P/F,6,5)+5102600(P/A,6,5)(P/F,6,7)
+4917000(P/A,6,10)(P/F,6,10)+540000(P/F,6,20)

NPV= -5090000+3889560(0.9434)+3844262(0.8900)+3792167(0.8396)
+3732264(0.7921)+3663378(0.7473)+5102600(4.2124)(0.6651)
+4917000(7.3601)(0.5584)+540000(0.3118)

NPV = +45.548.312

Net Present Value (NPV) >0, therefore the project is economically viable.

5 Conclusion

5.1 Introduction

Sigma Colliery is under increasing pressure from a variety of sources to adopt better methods and approach to their coal blending problem, particularly in the context of technical innovation. Whilst there is some data which confirms their efforts through their conventional sampling methods, there is also contradictory evidence. The final blend's ash content is outside the specification more often than not.

The literature study shows that although the trend towards the use of technology and more efficient blending models is recognized as important, it is not yet well-understood and is receiving comparatively little attention, particularly in the form of empirical research into more effective and economic coal blending solutions.

Through analysis and evaluation of the literature study and development of valuable implementation strategy there is acknowledgement that the principles presented are appropriate to the management of coal blending system and process redesign at sigma Colliery.

The document contains all the necessary literature for the purpose of understanding the problem, innovative and authentic ideas/concepts and a sound implementation plan. The proposed processes are advocated as process pitfalls were discussed are remedial measures were put in place. Literature on ash related failures proved that the cost of failure to supply within specifications coals, even by a small percentage can be disproportionately high.

5.2 Key Performance Indicators (KPI)

Key Performance Indicators help an organization define and measure progress towards a particular goal. A project's mission is analyzed, stakeholders identified, and goals defined, a way to measure progress towards those goals; KPIs are those measurements. Reh (2003) states that Key Performance Indicators are quantifiable measurements, agreed to beforehand, that reflect the critical success factor of a project. They will differ depending on the industry. They are usually long-term considerations.

The successful execution of the coal blending and process redesign for a steam generation plant will be indicated by certain changes in the following performance indicators:

- Cost – this refers to the cost incurred in turning a ton of coal into steam. A lower cost indicates a favourable performance of the new system.
- Increase in productivity – productivity denotes the amount of coal extracted, and after blending was within the ash content specifications.
- Increase in profitability – revenue generated through turning coal into steam taking into account the cost involved.
- Increase in customer satisfaction – the customer's report, Infrachem, of the coal quality will be used as a measure of the blending system's performance.
- Dependability – this refers to the constancy of the system's performance. Generally a more constant performance is preferred.
- Flexibility – this is the ability of the system to adapt to different kinds of variations such as speed and loading.
- Employee's opinion (surveys) – employees will have first hand experience of the performance of the new system. They will complete questionnaires (surveys), through these they voice their opinions regarding the new system and give improvement suggestions.
- System Errors – the number of errors will indicate the level of efficiency of the system.

The performance indicators should be monitored and evaluated as soon as the concepts are implemented. The data taken will indicate where the system is lacking. This will serve as an indication as to where improvements should be implemented.

5.3 Project Advantages

The project execution, through adhering to the scope and striving to deliver the deliverables could have the following advantages:

- Eliminate the erroneous sampling process.
- Save time (No sampling process).
- Effective control on the ash content.
- Save money (Boiler trips will be eliminated).
- Have an existing and proactive coal blending system.
- Have an organised coal blending station.
- State of the art and accurate coal scanning equipment.
- Increase the life span boiler.
- Have a controlled ash removal scheduled.

5.4 Conclusions

The deliverables outlined in the project proposal document were executed. The coal ash content determination problem was simplified, making it possible to formulate and implement a coal blending system. The system operation is driven by the model developed. The model serves as a tool used in the process of blending conveyed coal with stockpile coal. It is evident, through the cost analysis, that the project is feasible as the gain (return) is much larger than the loss (cost).

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