Potential and Technical basis for Utilising Coal Beneficiation Discards in Power Generation by Applying Circulating Fluidised Bed Boilers

Mohamed Belaid, Rosemary Falcon, Pasi Vainikka and Kamohelo V Patsa

Abstract—Coal continues to remain South Africa’s prime energy source with coal fired power generation by ESKOM (62 %) and gasification by SASOL (23 %) leading local coal consumption. Beneficiated coal is also exported (70 million tonnes) while raw sized coal is also consumed for cooking and heating in South Africa’s townships. Discard coal is currently being produced at annual rates in excess of 60 million tonne per annum. This is estimated to have already accumulated to more than 1-billion tonnes. Discard coal is a major concern to the department of mineral and energy regarding the potential environmental impact in the future. It should also be seen as a major resource that could provide economic opportunity. The purpose of this paper is to estimate the production and reservoir volumes of SA coal discards and their technical and economic potential application in large scale power generation through CFB combustion. It was found that whilst discard is a poor material, its varying range in heating value and current production rate makes it a potentially viable material for beneficiation towards electricity generation. It’s been found that beneficiating discard coal could come with some challenges e.g initial costs, but on the other hand it could present techno economic opportunities e.g harnessing new technologies to create employment. The study was carried out using Russian coal with high calorific value as a reference. CFB technology has excellent fuel flexibility and offers the opportunity to further reduce CO₂ emissions by co-firing coal-biomass. We investigated the emission trends of CO, CO₂, SOx and NOx, HCl and other volatiles environmental of discards firing in CFB

Keywords—CFB, Discards; emission trends.

I. INTRODUCTION

SOUTH Africa (SA) started to export coal in the early 1970’s. The export contractors required low ash material and for the first time the South African industry started to wash its products in large quantities. The discard was dumped and since then reasonable reserves of potentially useful discard coal has built up. The remainder of the discards resulted from double washing operations in coal industries [1].

To reclaim coal discards it’s essential that the discard characteristics are known and understood. Some of the characteristics that are to be considered are the discards calorific value, ash content, sulphur content, fixed carbon content and age of the discard [2].

There are at least two potential uses of coal: Firstly the beneficiation of coal discards to yield conventional coal products and secondly the combustion of raw discards in a fluidised bed combustor [3].

The primary reason for not burning coal already is that its only recently that boilers have been developed, which are able to use material nearly as abrasive as the average discard. In a nutshell South Africa has lacked the equipment for burning coal. However fluidised bed combustors are rapidly reaching the stage of technical development essential for their exclusive use in commercial power generation [1].

Discard coal has continued to accumulate over many years with current estimates stating that there’s approximately 1.5 billion tonnes of discard coal in South Africa. Since not much attention was placed in finding ways of beneficiating this material in the past due to the fact that discard coal is considered to be a poor quality material. As a result of that, discard coal has continued to accumulate over the years, occupying potentially useful land and polluting the environment i.e. spontaneous combustion and ground water contamination. Today’s challenge is to understand the composition and quantity of this material and hence investigate ways in which discard coal can be beneficiated.

II. METHODOLOGY

This work was conducted using the following steps:
- Site visits
- Interviews
- Use of previous coal discard inventory
- Data collection
- Sampling and testing of samples
- Discard coal combustion in circulating fluidised bed in a pilot plant using Russian coal as a reference.
III. RESULTS AND DISCUSSION

A. Estimate of the Overall Inventory of Discard Coal in South Africa

The following data were extrapolated from the 2001 inventory conducted by the department of minerals and energy (DME). The study aims to obtain new estimates of discard material over a 10 year period since 2001 to 2011. Rough estimates of the total tonnage from literature in 2011 revealed that there is close to 1.5 billion tons of discard present in South Africa. This has been produced at a rate of between 53.793 million tonnes to 60 million tonnes per year over the past 10 years. This production rate and the difference between the 2001 tonnage (1.1 billion) and the tonnage estimate in 2011 (1.5 billion) was used as the basis for the calculation of new estimates of the discard inventory in 2011.

A.1 Tonnage Estimates in year 2001 (DME Survey)

![Fig. 1 Discard dump tonnages from the 2001 survey, a) active sites, b) defunct sites](image)

Fig. 1 Discard dump tonnages from the 2001 survey, a) active sites, b) defunct sites

A.2 Tonnage Estimates in year 2011 (Present study)

Fig. 2 indicates the number of dumps against the tonnage produced, based on the assumption the dumps surveyed in 2001 are still active in 2011 by 100, 80 and 50 % respectively.

![Fig. 2 Estimate of discard dump tonnages , a)100 %, b) 80 %, c) 50 % active sites) in 2011.](image)

From Fig. 2 it can be seen that the number of active dumps contributing to discard production would have decreased from 32 dumps in Fig. 2 (a) to 26 dumps in Fig. 2 (b). If the number of active sites is reduced by 50 % from the 2001 survey, the estimate of active sites in 2011 is shown in Fig. 2 (c). This would result in the estimated tonnage from active sites for 2011 being 10% to 20 % lower.

The inactive discard dump sites would now fall into the category of defunct (inactive) dumps which have seized increasing in tonnage but still form a significant part of the overall inventory of discard coal.

![Fig. 3 shows the estimate of the number of inactive (defunct) dumps and their tonnage in 2011 assuming that only (80 % and 50 %) of the dumps which were active in 2001 are still active in 2011.](image)

Fig. 3 shows the estimate of the number of inactive (defunct) dumps and their tonnage in 2011 assuming that only (80 % and 50 %) of the dumps which were active in 2001 are still active in 2011.
It can be observed from both Figs. 3(a) and (b) that while there’s a decrease in the number of active dumps there’s also an increase in the amount of inactive sites, due to the fact that as dumps seize to increase in tonnage they are called inactive dumps. The number of defunct dumps would be 10% to 20% because some of the previously active sites would have become inactive over the past ten years, as some collieries would have closed down completely, or scaled down their operations over the past ten years.

B. Age of the Discard and Area Covered

It should be noted that the age of the discard material is important, as discard undergoes weathering over a number of years when it is exposed to the elements, there’s a percentage of discard that would have undergone significant weathering and will probably be of a poor quality for beneficiation.

C. Coal Discard Properties

The potential beneficiation of discard material towards power generation depends on the properties of the discard material in particular the calorific value and the ash content of the material. As this is important in determining the combustibility of the material and the possible technologies that could be employed to beneficiate the discard coal.
The coal discard produced calorific value ranges between 11 to 14 Mj/kg. This is close to the poor quality coal currently being beneficiated by Lethabo one of Eskom’s power stations which burns poor quality coal with a calorific value between 14 and 16 Mj/kg.

As for the ash content of the material, the highest tonnage contains 40% to 50% ash which could be beneficiated. The other significant tonnage falls within 20% to 30% of ash content which is within the combustible range of most coals.

**D. Discard Coal Behaviour in Circulating Fluidised Bed**

This study was conducted by firing Russian coal and discard coal in a pilot plant circulating fluidised bed, located in VTT testing centre in Jyvaskyla, Finland.

**D1. Analysis of discard coal tested**

<table>
<thead>
<tr>
<th></th>
<th>H2O (%)</th>
<th>Ash (%)</th>
<th>Volatile (%)</th>
<th>F/Carb on (%)</th>
<th>Cal Value Mj/kg</th>
<th>Total Sulphur (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russian Coal</td>
<td>3.2</td>
<td>15.4</td>
<td>34</td>
<td>47.4</td>
<td>26.6</td>
<td>0.2</td>
</tr>
<tr>
<td>SA Coal Discard</td>
<td>0.9</td>
<td>73.5</td>
<td>12.8</td>
<td>12.8</td>
<td>5.04</td>
<td>0.6</td>
</tr>
</tbody>
</table>

**D2. Combustion Efficiency**

**D3. Emission impact**

The following figures highlights the emission impact of discard coal in comparison with Russian Coal.
The emission trends shown above indicates that discard coal of a lower quality and high ash content can yield results well below minimum requirements limits, therefore discard coal of better quality or blended with other types of coal could be used for power generation.

**E. Feasibility Analysis of Electricity Generation from Discard Coal**

The feasibility study was carried out using one of Eskom’s largest power stations (Lethabo power station) in the Vaal Triangle. It is one of the few plants in South Africa which can burn poor quality coal close to discard with a calorific value of 14MJ/kg and ash 38% content. This suggests that most of the other power stations are currently unable to beneficiate the remainder of the potentially combustible discard in the region of about 1.5 billion tonnes. This plant can generate up to 3600 MW at full capacity, burning close to 50 000 tonnes/day of coal. If the plant buys raw coal at a cost of R100 to R200 per tonne of coal, amounting to approximately 1825 million rands per year on the purchase of coal. Considering the fact the amount of good quality coal is diminishing and existing reserves are limited.

**F. Discard Coal Using CFB Boiler Plant Proposal**

The feasibility study was carried out using one of Eskom’s largest power stations (Lethabo power station) in the Vaal Triangle. It is one of the few plants in South Africa which can burn poor quality coal close to discard with a calorific value of 14MJ/kg and ash 38% content. This suggests that most of the other power stations are currently unable to beneficiate the remainder of the potentially combustible discard in the region of about 1.5 billion tonnes. This plant can generate up to 3600 MW at full capacity, burning close to 50 000 tonnes/day of coal. If the plant buys raw coal at a cost of R100 to R200 per tonne of coal, amounting to approximately 1825 million rands per year on the purchase of coal. Considering the fact the amount of good quality coal is diminishing and existing reserves are limited.

**Table II**

<table>
<thead>
<tr>
<th>Fuel consumption</th>
<th>Heating value (cv)</th>
<th>Total fuel energy input</th>
<th>Assumed efficiency</th>
<th>Total energy output</th>
<th>Power output</th>
<th>Power Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kg/hr)</td>
<td>(MJ/kg)</td>
<td>(MJ/hr)</td>
<td>(n)</td>
<td>(MJ/hr)</td>
<td>(MW)</td>
<td>(TW)</td>
</tr>
<tr>
<td>2.08</td>
<td>8</td>
<td>1.67</td>
<td>0.4</td>
<td>6.67</td>
<td>1.85</td>
<td>1.85</td>
</tr>
<tr>
<td>2.08</td>
<td>9</td>
<td>1.87</td>
<td>0.4</td>
<td>7.50</td>
<td>2.08</td>
<td>2.08</td>
</tr>
<tr>
<td>2.08</td>
<td>10</td>
<td>2.08</td>
<td>0.4</td>
<td>8.33</td>
<td>2.31</td>
<td>2.31</td>
</tr>
<tr>
<td>2.08</td>
<td>11</td>
<td>2.29</td>
<td>0.4</td>
<td>9.17</td>
<td>2.54</td>
<td>2.54</td>
</tr>
<tr>
<td>2.08</td>
<td>12</td>
<td>2.50</td>
<td>0.4</td>
<td>1.00</td>
<td>2.77</td>
<td>2.77</td>
</tr>
<tr>
<td>2.08</td>
<td>13</td>
<td>2.71</td>
<td>0.4</td>
<td>1.08</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>2.08</td>
<td>14</td>
<td>2.92</td>
<td>0.4</td>
<td>1.17</td>
<td>3.23</td>
<td>3.23</td>
</tr>
</tbody>
</table>

Beneficiated discard coal could be used as a feed into CFB boilers for power generation and will provide a platform for wider application at the source. Discard coal beneficiation has its own challenges and benefits.

- Beneficiation challenges:
  - Lack of technological developments
  - Composition of the discard material
  - Initial capital cost
  - Environmental concerns
  - Location of the discard

- Beneficiation benefits:
  - Techno-economic
  - Job creation
  - Environmental impact
  - Regional development
  - Localisation benefit

**IV. CONCLUSION**

Vast reserves of discard coal have accumulated in South Africa since the last inventory of 2001, there’s close to 1.5 billion tonnes in existence. From the study it became apparent that one of the looming challenges regarding discard coal is putting this ever accumulating material to use. This discard coal was found to range in age and composition falling within a range of 2MJ/kg and 14 MJ/kg in calorific value. Hence, amongst many other possible uses of this material, beneficiating discard coal towards power generation was found to be one of the most viable alternatives. One of the proposed technologies for beneficiating such poor quality material is the circulating fluidised bed boiler which has been
proven to be more efficient than the current PF system. CFB technology is increasingly establishing itself as the technology of choice where fuel flexibility and lime stone addition as sorbent eliminates the capital cost of desulphurisation unit used in PC technology. Lagiza plant in Poland is a testimony to the maturity of the technology. It was found that benefits that could result from beneficiating discard coal are cheaper power generation and techno economic benefits with a possible plant energy output of 3200 MW similar to the current output archived at lethabo power station.

ACKNOWLEDGMENT

The authors acknowledge VTT research Centre, Finland for using their testing facility, Coal and Carbon research group at Wits University for funding the research and the Department of Chemical Engineering, University of Johannesburg for funding the conference attendance.

REFERENCES