Indramayu 3 x 330 MW CFPP Coal Yard Management Optimization with K-Means Clustering

S Andria

1Engineering Department, PT Pembangkitan Jawa-Bali UBJ O&M Indramayu 3 x 330 MW CFPP, West Java, Indonesia
Corresponding email: syarief.andrian@ptpbj.com

Abstract. Coal yard management is part of the generation management to ensure that coal supply to the unit can continue to be met. The coal entering the boiler is regulated considering various coal characteristics that differ between suppliers with coal mixing strategies, to ensure the generating unit works following the performance target. One of the generating units operated by PT Pembangkitan Jawa Bali (PJB) is the Indramayu 3 x 330 MW coal-fired power plant (CFPP). Using 1507 data shipments of PLTU Indramayu from January 2017 to June 2020, a more straightforward coal yard management method can be analyzed. Data were analyzed using k-means clustering by using important parameters from coal property data. Important parameters used are Gross Caloric Value (GCV), Hardgrove Grindability Index (HGI), theoretical air for combustion, and slagging index. From the modeling with k-means clustering, the six optimal clusters are obtained. These six clusters are much simpler than before, managed in 16 clusters in the coal yard. Simplified coal yard management will have a significant impact on operational efficiency.

1. Introduction
Coal yard management is part of coal supply chain management as primary energy to ensure minimum unit operation within 22 days of operation (HOP). Coal yard management is a part of coal management within the scope of power generation, including the unloading, storage, and use of coal, which in the work environment of PT. PLN (Persero) activities are carried out under SPLN K5: 006 2018 Tata Kelola Pembongkaran, Penyimpanan dan Pemakaian Batubara [1]. The storage of coal is carried out to control the quality of the coal both according to the default specifications of coal and control changes in quality due to weather through the First in first out (FIFO) method.

Indramayu coal-fired power plant has a capacity of 3 x 330 MW. It is near the load center of the Java-Bali electricity system so that it has a high Capacity Factor (CF). The operation of the Indramayu 3 x 330 MW CFPP, which is almost always in high load, requires coal supply of up to 3 x 180 tons/hour, or nearly 13,000 tons of needs per day. Daily coal needs are met through the coal yard's loading mechanism served by two Stacker Reclaimers (SR) and in certain circumstances with direct unloading of two Ship Unloaders (SU), which under normal conditions functions to unloading coal to the coal yard.
Table 1. Indramayu 3 x 330 MW CFPP 2019 Coal Shipment (Source: Internal Data)

| No | Suppliers            | Count Shipment | Volume (MT) |
|----|----------------------|----------------|-------------|
| 1  | AI                   | 69             | 610260      |
| 2  | BA49                 | 135            | 1196801     |
| 3  | EEI                  | 35             | 270227      |
| 4  | KII                  | 22             | 203786      |
| 5  | PLNBB LRC            | 94             | 728603      |
| 6  | PLNBB MRC            | 35             | 331913      |
| 7  | RAP                  | 19             | 140189      |
| 8  | TITAN                | 5              | 36684       |
| 9  | TITAN LRC            | 9              | 64628       |
| 10 | TITAN MRC            | 24             | 171684      |
|    | TOTAL                | 447            | 3754776     |

Arrangement of coal at Indramayu 3 x 330 MW CFPP is carried out under the Standard Operating Procedure (SOP) of Coal Arrangement at Coal yard, which is divided into sixteen areas based on coal suppliers. One of the main KPIs in the generation is NPHR and BPP, so in coal yard management, the only parameter used is the calorific value of coal.

Coal yard management activities are carried out by 2 (two) stacker reclaimer (SR) assisted by bulldozers and excavators. The machine is used to help steer coal because of the limited SR boom range, pile tapping, and self-combustion prevention activities. The more the division of coal yard area will demand SR was traveling more frequently, as well as the demand for heavy-equipment support.

2. Essential Coal Properties For Indramayu 3 X 330 Mw Cfpp

Before coal is sent to the plant, maximum one day before the Time Arrival (TA), the supplier must submit a Certificate of Analysis (CoA) and a Certificate of Weight (CoW). In the COA, the measured quality parameters of the coal, and the COW explains the volume. Coal quality is measured by several parameters, namely total moisture, proximate analysis, total sulfur, caloric value, ultimate analysis, ash fusion temperature, and ash analysis. These parameters are essential considerations in designing
boilers, and in the operation of boilers with varied coal, these parameters must be considered to obtain the expected coal mixing.

At present, coal yard management is carried out by dividing the coal yard area into sixteen areas based on suppliers. This division assumes that each supplier supplies coal with a consistent calorific value. This division also considers the main KPI of the plant now is NPHR, which calculates the amount of incoming energy divided by the value of the generated energy generated. The fact is that the calorific value of each supplier is currently inconsistent. Besides, several coal properties significantly affect the operation of the unit. Other properties besides coal calorie value that are considered necessary are Hardgrove grindability index (HGI), theoretical air for combustion, and slagging fouling index.

2.1 Gross Caloric Value (GCV)
The net work output of the power plant is simply the difference between the total heat output of the plant and the total heat input [2].

\[ w_{net, out} = Q_{in} - Q_{out} \quad (kJ) \]  

The heating value is calculated from the heat energy released on complete combustion. Higher Heating Value (HHV) is calculated from the calorimeter bomb, and Lower Heating Value (LHV) is calculated from HHV minus the latent heat of the water vapor contained [3]. The calorific value of coal is the most critical parameter, which is a reference to how the energy contained in each mass unit is then converted into electrical energy in a steam power plant engine. The higher the GCV value, the greater the energy contained in the mass unit.

Indramayu Power Plant is designed to operate at a heating value of 4550 kCal/kg. Using coal with a lower GCV requires more quantities to produce the same power. At some point, the boiler volume is no longer able to accommodate the coal volume and the combustion air volume to maintain the same energy requirements. The calorific value of the coal put into the bunker must be considered to ensure the unit can process coal in an appropriate amount to maintain the desired output and the best possible performance.

2.2 Hardgrove grindability index (HGI)
The relative ease with which coal can be pulverized depends on the coal strength and is measured by the Hardgrove grindability index (HGI) [4]. The higher the HGI value of coal, the easier it will be to be pulverized.

![Figure 3. Coal combustion process [5].](image-url)
The process of smoothing coal into powder is carried out by a pulverized mill designed for certain HGI and specific capacities. HGI is an essential factor that should be a concern because the mill’s failure to produce the desired powder size can cause an incomplete combustion process, which will have a direct impact on boiler performance. When the size of the powder (coal fineness) is not met, the combustion reaction in the burner will require a longer time. The combustion reaction should occur in the furnace. When the combustion reaction takes too long, then the combustion reaction is not finished and causes the fuel energy is not maximally absorbed by the boiler tube.

2.3 Theoretical air for combustion

Combustion is defined as the rapid chemical combination of oxygen with the combustible elements of a fuel. There are just three combustible elements of significance in most fossil fuels: carbon, hydrogen, and sulfur [6]. The stoichiometric volume of oxygen required for complete combustion of fuel mass unit is obtained by summing volumes of oxygen required for the combustion of fuel components from the preceding equations. The presence of oxygen in fuel composition can be noticed, having mass participation of \( (O_i) \), and this quantity should be no longer introduced from the outside into the furnace. The stoichiometric volume of oxygen required for combustion is [10]:

\[
V_{O_2}^0 = \frac{22.41}{100} \left( \frac{C_i}{12} + \frac{H_i}{4} + \frac{S_i-O_i}{32} \right) \left[ \frac{m^3_{O_2}}{kg_fuel} \right]
\]

(2)

From the ultimate analysis, the fuel composition is obtained in percent weight. The oxygen demand for combustion can be calculated from the C, H, O, N, and S components of coal. The combustion air volume factor is an especially important parameter related to the fan boiler’s ability to supply air requirements. The air demand for each type of coal varies, so there will be a point where the air demand is too high so that the fan cannot complete it. The impact of unmet air requirements is an incomplete combustion reaction until the output power must be reduced (derating).

2.4 Na2O

Slagging is the formation of molten, partially fused, or resolidified deposits on furnace walls and other surfaces exposed to radiant heat. Fouling is defined as the formation of high temperature bonded deposits on convection heat-absorbing surfaces, such as superheaters and reheaters, that are not exposed to radiant heat [6]. Slagging and fouling deposits will cause a decrease in boiler performance. The slagging and fouling potential can be predicted from coal ash analysis and calculated using the slagging index and fouling index.

![Figure 4. Deposition zones in a coal-fired boiler [6].](image)
The slagging index for lignitic ash ($R_s$) is based on ASTM ash fusibility temperatures. The index is a weighted average of the maximum hemispherical temperature (HT) and the minimum initial deformation temperature (IT). The fouling classification for lignitic ash coals is based on the sodium content in the ash. (Babcock & Wilcox Company. (1923)). The coal used in the Indramayu 3 x 330 MW CFPP has a relatively low slagging index value. Still, the value of the fouling index is quite varied, so it becomes an important consideration in the use of coal.

3. Result And Analysis

The popular K-means algorithm is a partitioning algorithm that iteratively moves k centroids until a termination condition is met. Typically, these centroids are initially chosen at random. Documents are assigned to the cluster corresponding to the nearest centroid. Each centroid is then recomputed. The algorithm stops when the centroids move so slightly that they fall below a user-defined threshold, or a required information gain is achieved for a given iteration [7].

![Figure 5. DB Index for the model](image)

The Davies-Bouldin (DB) index evaluates the dispersion of data based on the distances between cluster centroids [8]. The measure can be used to infer the appropriateness of data partitions and, therefore, be used to compare the relative appropriateness of various data [9].

Using Rapidminer data processing software, the clustering method is processed by calculating four main parameters that are considered particularly important. That four parameters, namely Gross Caloric Value (GCV), Hardgrove Grindability Index (HGI), theoretical air for coal combustion, and sodium content in ash. The performance of the clustering generated was evaluated with the Davies Bouldin Index (DBI). Performance evaluation based on the number of clusters is described in the figure. It can be concluded that the most optimal number of clusters is six clusters.

| Attribute        | cluster_0  | cluster_1  | cluster_2  | cluster_3  | cluster_4  | cluster_5  |
|------------------|------------|------------|------------|------------|------------|------------|
| GCV ARB          | 4668.28    | 4733.81    | 4752.58    | 4225.21    | 4829.71    | 4491.09    |
| HGI              | 66.68      | 60.38      | 57.73      | 56.90      | 42.97      | 51.59      |
| Theoretical Air  | 7.33       | 7.71       | 7.74       | 6.99       | 7.53       | 9.60       |
| Na2O             | 0.44       | 1.49       | 0.51       | 0.46       | 1.55       | 0.38       |
| Count shipment   | 144        | 108        | 367        | 821        | 35         | 32         |
| Percentage       | 9.56%      | 7.17%      | 24.35%     | 54.48%     | 2.32%      | 2.12%      |

The results of k-Means Clustering modeling with the number of clusters are 6, described in the centroid cluster table in the table. Cluster_3 is the largest cluster with a percentage of more than 50%,
with GCV centroid at 4225.21 kCal/kg. Cluster_3 can be categorized as a low-rank coal cluster. In the division of the coal yard area, cluster_3 can be placed in one full side. Cluster_3 is also the cluster with the lowest HGI value among other clusters and is an essential consideration in its use, which will impact the ability of the pulverized mill.

Figure 6. Gross caloric value (GCV) centroid

Figure 7. Hardgrove grindability index (HGI) centroid
The division of the coal yard area for the other side can be arranged in a row as follows: cluster_5, cluster_0, cluster_1, cluster_2, cluster_3, and cluster_4. Such a sequence is carried out following the GCV centroid sequence, according to the procedure before this. Cluster_5 is placed slightly apart with considerations including small volume, low GCV value, and the most important is the character in combustion that requires a sizeable theoretical air for combustion. Cluster_5 needs special attention because this coal will cause a massive demand for fan work. Cluster_5, in its use, can be mixed with coal from other clusters, so that fan work is not within its maximum limits.

Cluster_4, in its use, needs special attention to the character of HGI coal in this cluster. The lowest HGI value compared to other clusters requires massive performance on the pulverized mill. The use of coal in this cluster is done on units with pulverized mill performance in good condition or mixed with other coal clusters with higher HGI.

Clusters_0, cluster_1, and cluster_2 have a large enough volume and have the same GCV characters. However, the use of cluster_0 coal is done by taking into account the pulverized mill's ability because of the low HGI value. The use of cluster_1 must pay attention to the ability of bottom ash handling because the Na2O value is higher than coal from other clusters. The high Na2O content will produce combustion with large slagging volumes.

Figure 8. Theoretical air for combustion centroid

Figure 9. Na2O centroid
4. Conclusion
The results of the analysis using k-means clustering on 1507 data shipments to the Indramayu 3 x 330 MW CFPP from January 2007 to June 2020 can be categorized into six data clusters based on four essential parameters namely GCV, HGI, theoretical air for combustion and slagging index. The coal yard management method using k-means clustering provides a simpler coal yard zoning. With a simpler coal yard management, it will improve operational efficiency. Some potential savings obtained from this clustering include heavy equipment fuel costs, coal-handling facility maintenance costs due to fewer operating hours, and human resources cost from reducing the number of operators.

Compared to the previous zoning system, the clustering method is more flexible with coal planning going forward, which will focus on using coal whose calorific value is lower. This method also considers important parameters for boiler operations to have a positive impact on boiler performance.

Many researchers have used analytical data to analyze power plant operations [11]. The use of data analysis along with the 4 pillars of transformation of PT. PLN (Persero) especially the lean pillar, with a digital power plant as one of the driving forces. With a very large data base, the potential for
optimizing power plant performance using data analysis is very large, not limited to coal yard management as discussed in this article.

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