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Optimization of Coal Blending to Reduce Production Cost and Increase Energy Efficiency in PT. PJB UP PAITON Power Plant

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Abstract: *The productivity level of the electricity production is an important indicator in the power plant efficiency. A chase study in this research was choosen at coal power plant PT PJB UP Paiton which is the productivity level of the generated electricity decreases until below the production target level. It due to several factors such as quality of coal and plant design. Depletion of coal heating value (low rank coal) reduce total amount of enerated heat in boiler and finally increase unburned carbon, plant inefficiency, as well as the high production cost. On the other hand, utilizing the high rank coal cause more expensive price. Therefore, the optimiation of coal blending to obtain more plant efficiency and lower production cost is required. This research focus on optimization of low and high rank coal blending that can decrease the production cost and increase plat efficiency. The blending model was built by utilizing Finite Impulse Response Neural Network (FIR-NN) and variable selection is perform using Priciple Component Analys is (PCA) and Partial Least Square (PLS). The result of optimization resulted a decreasing the production cost up to 342 IDR/kWh.*

I. Introduction

According to the International Energy Agency (IEA), the global energy demand is expected to grow at a rate of 1.5% a year by 2030, and the use of coal is expected to rise by over 60% to the year of 2030. Most of this is in the power generation sector, with coal's share in global electricity generation set to increase from 41% to 44% by 2030 [1].

Among all of the parameters are available to describe coal, the "rank" of coal is always taken into consideration when evaluating any coal quality. Rank is also a measure of carbon content as the percentage of fixed carbon increases with extent of metamorphism which indicated how much energy content [2]. Recently, the exploration of coal resources has been concentrated on high-rank coal. With the growing demand for energy and the sharp decrease in the availability of high-rank coal resources, the highly efficient conversion of low-rank coal has become even more essential [3].

In order to develop technology of low rank coal utilization, one of the way is blending it with other fuels. Vie A. Cundy and Dupree Maples have been examined the combustion phenomena of lignite-fuel oil mixtures. Blending ratio up to 35 wt% of lignite was blended with number 6 fuel oil. The blending were resulting a stable fire, compact flame with the characteristics of a heavy residual fuel oil flame [4].

It inspired, PT PJB UP Paiton to solve one of the problems at the coal power plants ie the production cost more than 395 IDR/kWh that is higher than production target. The cause of the high production cost is the quality coal, low power plant efficiency as well as the unsatisfied composition of the coal blending. Therefore, the research on optimization of coal blending is required to find out the optimum blending low and high rank coal.

1.1. Coal Formation

Coal was formed from prehistoric plants, in marshy environments, some tens or hundreds of millions of years ago. The presence of water restricted the supply of oxygen and allowed thermal and bacterial decomposition of plant material to take place, instead of the completion of the carbon cycle. Under these conditions of anaerobic decay, in the so-called biochemical stage of coal formation, a carbon-rich material called peat was formed. In the subsequent geochemical stage, the different time-temperature histories led to the formation of coals of widely differing properties, as summarized in **Table 1** [5].

Table 1 Carbon content and age of different coals

Coal type	Approximate age (years)	Approximate carbon content (%)
Lignites	60,000,000	65-72
Subbituminous coals	100,000,000	72-76
Bituminous coals	300,000,000	76-90
Anthracites	350,000,000	90-95

1.2. Properties of Coal

Although, it is customary to use the word 'coal' in the singular, if we assembled a collection of coal specimens from around the world, we would find that this word is actually applicable to materials having a rather wide range of properties. One sample might be a wet, easily crumbled brown material looking like partially decayed wood. Another would be a very hard, glossy black, lustrous material. A third would be a soft, dull black, waxy solid. The heating values of these samples would range from about 5000 to about 15,000 BTU/lb [5]. In a sense, there is no such thing as coal, if we use the word to imply a single, uniquely defined material. Rather, we might say that there are coals, implying a family of substances having both similarities and differences among them.
Because of wide variations in the composition and properties of coals, a classification system is needed to describe the different kinds available for use in homes and power plants. In PT PJB Paiton, coal can be classified as the value Net Plant Heat Rate (NPHR) i.e. low rank coal (<5000 kcal/kWh) and high rank coal (>5000 kcal/kWh). **Table 2** described classification of coal by rank [2].

Table 2 ASTM Coal Classification by rank

Class and group	Fixed carbon (%)	Volatile matter (%)	Heating value (BTU/lb)
I. Anthracite			
1. Meta anthracite	>98	<2	
2. Anthracite	92-98	2-8	
3. Semi anthracite	86-92	8-14	
II. Bituminous			
1. Low volatile	78-86	14-22	
2. Medium volatile	69-78	22-31	
3. High volatile A	<69	>31	>14,000
4. High volatile B			13,000-14,000
5. High volatile C			10,500-13,000
III. Subbituminous			
1. Subbituminous A			10,500-11,500
2. Subbituminous B			9500-10,500
3. Subbituminous C			8300-9500
IV. Lignite			
1. Lignite A			6300-8300
2. Lignite B			<6300

1.3. Heating Value

The heating value of a fuel is the amount of heat recovered when the products of complete combustion of a unit quantity of fuel are cooled to the initial temperature (298 K) of the air and fuel. As the heating value of fuel increases, the heat content delivered to the burner increases. The heat of combustion of a fuel is also called its potential heat.
When a fuel is burned in oxygen saturated with water vapor, the quantity of heat released is known as the high heating value (HHV), or gross calorific value (GCV), of fuel. When the latent heat of water vapor contained in the combustion products is subtracted from the HHV we get the low heating value (LHV) or net calorific value (NCV) of fuel. In a laboratory, the HHVs of solid and liquid fuels are determined at constant volume and those of gaseous fuels are determined at constant pressure. Combustion in a furnace, however, takes place at constant pressure [6].

$$HHV_{coal} = 33.823C + 144.251\left(H_2 - {}^{O_2}/_{7.937}\right) + 9.419S \quad (1)$$

Once the value of HHV_{coal} is known, either from laboratory determination or from Dulong's formula, the LHV_{coal} is then calculated as follows:

$$LHV_{coal} = HHV_{coal} - 2.44(8.937H + M) \quad (2)$$

where C, H, O, S, and M correspond to carbon, hydrogen, oxygen, sulfur, and moisture content of coal, respectively, expressed in parts by weight of each constituent, and heat of condensation of water vapor at 298 K is 2.44 MJ/kg.

1.4. Pulverizer

Pulverization is currently the favored method of preparing coal for burning. Mechanically pulverizing coal into a fine powder enables it to be burned like a gas, thus allowing more efficient combustion. Transported by an air or an air/gas mixture, pulverized coal can be introduced directly into the boiler for combustion [7].

There are several pieces of equipment involved in processing coal to be burned in this fashion. **Fig. 1** is a simplified diagram detailing this equipment in a direct-fired coal burning system. In this study there are 5 pulverizers in operation based on real condition in the field.

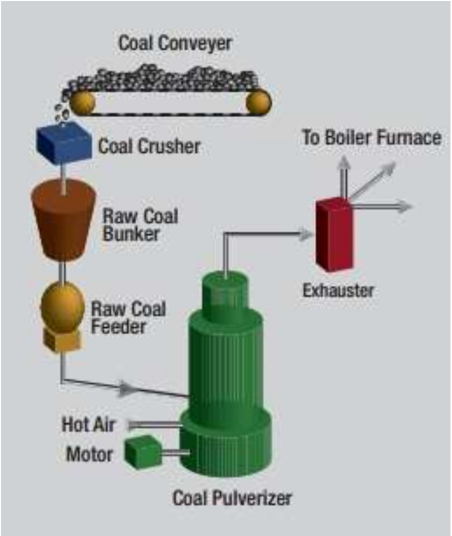

Fig. 1 Simplified diagram detailing a direct-fired coal burning system

1.5. Neural Network

Neural networks are information-processing systems. Neural networks can be thought of as “black box” devices that accept input and produce output. Each neural network has at least two physical components: connections and processing element (neuron). The combination of these two components creates neural networks. In system identification viewpoint, there are some advantages of neural networks to develop the model i.e. neural networks have greatest promise in the real of nonlinear problem, neural networks are trained using past data records from the system under study, and multivariable systems

The neurons by themselves are not very powerful in terms of computation or representation but their interconnection allows encoding relations between the variables giving different powerful processing capabilities. The connection of several layers gives the possibility of more complex nonlinear mapping between the inputs and the outputs. This capability can be used to implement classifiers or to represent complex nonlinear relations among the variables. The most common of neural networks structure is Multi Layer Percepton (MLP). Fig. 4 illustrates the example of MLP networks, which consist of input, hidden and output layer.

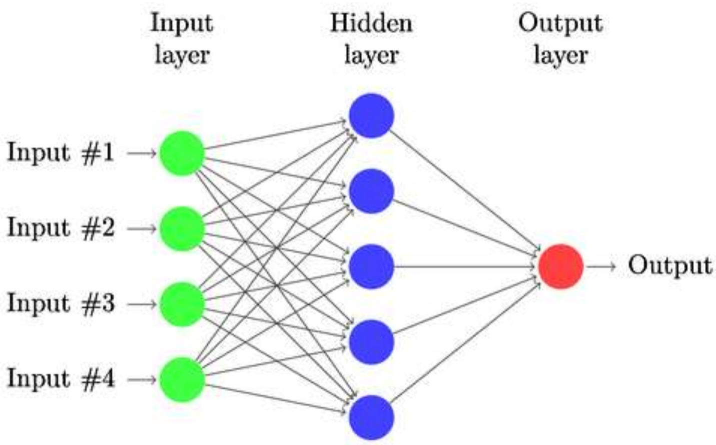

Fig. 2 FIR Neural Network architecture

II. Method

This research was conducted on the composition of the selection between low rank coal and high rank coal as a fuel in boilers. **Table 3** and **Table 4** is a composition in January to June and performance test results in January.

Table 3 Data of coal composition

Month	High Rank (%)	Low Rank (%)	Heat (kcal/kg)	Coal Cost (Rp/kg)
January	29	71	5050.63	726
February	49	51	5034.20	743
March	37	63	5153.51	745
April	40	60	5176.23	781
Mei	44	56	5120.53	769
June	64	36	5083.57	713

Table 4 Results of performance test on January

No	Parameter	Unit	N & C	After JBIC	Last Month	Month of January
1	Gross Generator Output	KW	401,605	406,000	399,500	395,500
2	Own Consumption	KW		31,038	28,972	26,736
3	kWh Netto	KW		374,962	370,528	368,764
4	Heating Value HHV	Kcal/Kg	6,040	4,903.62	5,105.00	5,022.00
5	Coal Flow	kg/h	127,371	189,764	188,547	188,000
6	Mill in Service	Unit	4	5	4	4
7	RH 1	%	0	0	50	50
8	RH 2	%	100	100	50	50
9	NPHR	kCal/kWh	2,272.71	2,481.67	2,597.73	2,560.27
10	Gross SFC	kg/kWh	0.35	0.47	0.47	0.48
11	Thermal Efficiency (Nett)	%	37.84	34.65	33.11	33.59
12	% O2 Leaving Economizer	%		3.15	1.13	2.37

From obtained data that is in field relationship between the composition of the coal with heating value, this relationship is used as a model in the selection of the appropriate compositions by minimizing the total production cost.

III. Result and Discussion

Fuel data on every coal feeder indicate on the Table. The best percentage of low rank is 42.19% and the smallest is 29.73%.

Table 5 Coal blending each feeder

Total Mass	A	B	C	D	E	% Low Rank	% High Rank
49488144.00	10561202.00	10651354.00	7636141.00	10228934.00	10410513.00	42.19	57.81
49575905.00	10578777.00	10668938.00	7653674.00	10246470.00	10428046.00	42.19	57.81
49667809.00	10597144.00	10687119.00	7672148.00	10264927.00	10446471.00	42.18	57.82
49752004.00	10614232.00	10703048.00	7689209.00	10281979.00	10463536.00	42.18	57.82
49842477.00	10632195.00	10721663.00	7707166.00	10299952.00	10481501.00	42.18	57.82
36559258.00	8593383.00	6433776.00	7009428.00	7430558.00	7092113.00	37.92	62.08
36660239.00	8613490.00	6454045.00	7029622.00	7450750.00	7112332.00	37.93	62.07
36756323.00	8632612.00	6473446.00	7048822.00	7469936.00	7131507.00	37.93	62.07
36850653.00	8651587.00	6492380.00	7067644.00	7488737.00	7150305.00	37.94	62.06
36951559.00	8671731.00	6512668.00	7087793.00	7508892.00	7170475.00	37.95	62.05
56394891.00	13267803.00	8416762.00	14089414.00	6656687.00	13964225.00	26.73	73.27
56493288.00	13288372.00	8437376.00	14109888.00	6672987.00	13984665.00	26.75	73.25
56585602.00	13307465.00	8456663.00	14129115.00	6688372.00	14003987.00	26.76	73.24
56680184.00	13327190.00	8476480.00	14148797.00	6704102.00	14023615.00	26.78	73.22
56771567.00	13346875.00	8495915.00	14167810.00	6719040.00	14041927.00	26.80	73.20

The next step is mapping the relation between four variables using PCA and PLS. The scatter plot in **Fig. 2** shows that net plant heat rate is proportional amount coal mass and inverse relation with percent low rank.

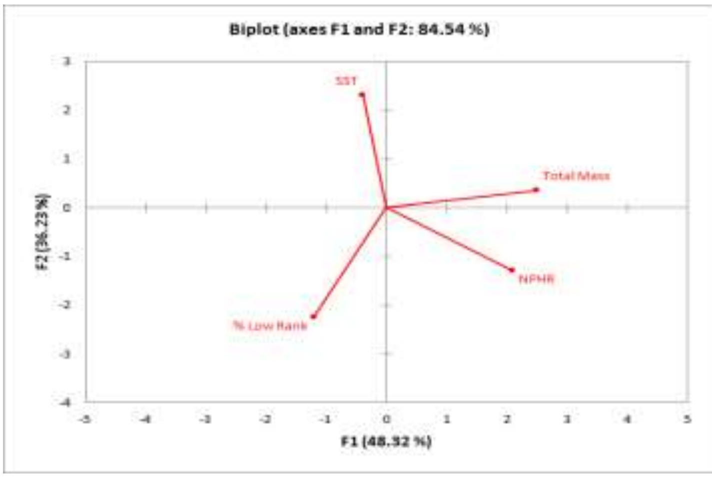

Fig. 3 Scatter plot using PCA

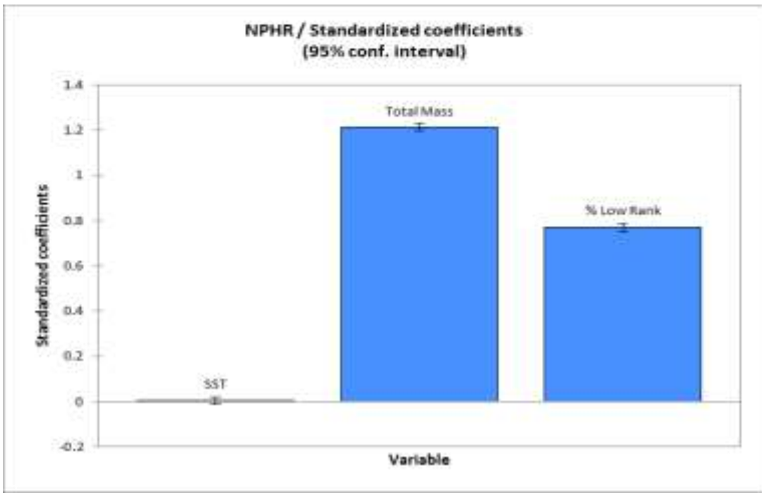

Fig. 4 Relation between net plant heat rate (Y) and % low rank (X)

Refer to **Fig. 3** provided by PLS, the VIP number between net plant heat rate (Y) and % low rank (X) is about 0.77. It was shown that the net plant heat rate and fouling correlation is searchable due to in grey area. VIP number more than 1 indicate the strong relation, bellow 0.5 indicate weak relation and VIP numbers in between need more investigation.

More investigation to predict the correlation between variable are utilizing the neural network (NN). Neural network used 10 hidden neurons like as shown **Fig. 5**. With initial value is taken randomly so that it will be got blending ratio with low and high rank coal 80:20.

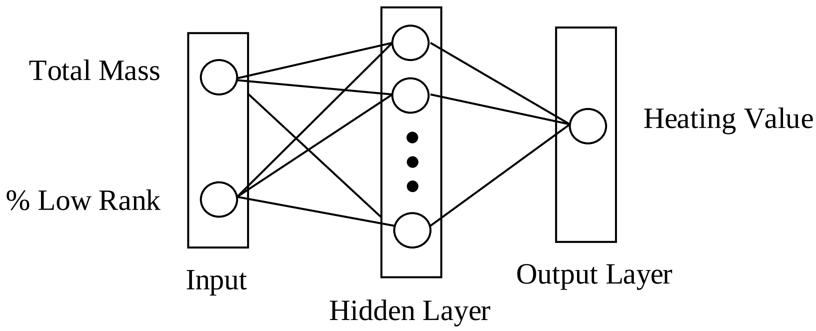

Fig. 5 Layer neural network

The results of optimization indicating blending composition between low rank and high rank that optimal for cost production is 20:80 up to 342 IDR/kWh. The fuel cost that can be saved up to 132 billion IDR per year or 11 billion IDR per month such as shown on **Table 6**. By setting demand appropriate fuel air with coal consumption billion per month then it can make savings cost production amounted to 0.42% (1.61 IDR/kwh) for unit 1 and 0.75% (2.88 IDR/kwh) for unit 2 as shown **Table 7**.

Table 6 potential savings of coal blending ratio 80:20

Coal consumption	After optimization	Before optimization	Amount coal price after optimization (IDR)	Coal price before optimization (IDR)	Difference price (IDR)
250,000	2,400,000	1,548,000	1,577,876,693,818	1,017,730,467,513	560,146,226,305
	600,000	1,452,000	487,625,790,000	1,180,054,411,800	692,428,621,800
Total	3,000,000	3,000,000	2,065,502,483,818	2,197,784,879,313	132,282,395,495.00

Table 7 The effect of air burned requirement to unburned carbon

Unit	Before Optimization	After Optimization	Heat (kcal/kWh)	Saving of production cost (IDR/kWh)
Unit 1	1.26%	0.81%	11.08	1.61
Unit 2	1.52%	0.72%	19.57	2.88

IV. Conclusions

The optimization results show that by blending ratio 80:20 between low rank coal and high rank coal resulted the production cost decreased to 342 IDR/kwh or equivalent 135 IDR/Cal. Provision of fuel cost savings of approximately 132 billion IDR per year or 11 billion IDR per month. In ideal fuel to air ratio, it can save BPP amounted to 0.42% (1.61 IDR/kwh) for unit 1 and 0.75% (2.88 IDR/kwh) for unit 2. The monthly savings of production due to this coal blending optimization are 560E6 and 692E9 for unit 1 dan 2, respectively.

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