The Leaching Characteristics of Coal Combustion Products (CCPs) from Indonesian Coal Power Plants

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Abstract

The large quantity of Indonesian coal combustion products (CCPs) will likely increase drastically and potentially be a serious problem in the future. This research aims to measure the element content of coal and CCPs, to assess leaching behavior and investigate the concentration level of heavy metals in leachate through TCLP, to analyze the correlation between the element content of coal, CCPs, and leachate of CCPs.

The resulting analysis of average element content on coal shows that the dominant element content was boron. Moreover, the distribution of heavy metals tended to enrich to be fly ash. The concentration level of heavy metals on fly ash and bottom ash leachates from all the power plants generally was much lower than the standard threshold. The significant level of concentration on fly ash and bottom ash was shown by boron. The concentration levels of heavy metals of coal ash leachates from two power plants were also much lower than the standard limit. The correlation between the element content of parent coal and CCPs pointed to no correlation between the variables. The element content of coal had no correlation to the concentration of CCPs leachate excluding nickel and chromium on bottom ash. Finally, it is recommended to assess other heavy metals concentration such as arsenic, mangan and selenium on CCPs leachate and further conduct a long-term study about the characteristics, leaching behavior of heavy metal leachate and, its effects on the environment.

Keywords: Coal combustion products, Leaching characteristics, Element content, Concentration level

1. INTRODUCTION

The development of coal power plants in Indonesia has produced coal combustion products (CCPs) in a huge number.The generating by coal power plants will increase dramatically from 50 TWh to 320 TWh in 2020 and the supply of coal will be 108.3 million tones per year[1]. It is predicted that total CCPs will be nearly 10.8 million tons in the same year. A large number of CCPs will potentially be a serious problem in the future owing to the requirements for storage. During the transport, disposal, and storage phases, the residues from CCPs are subjected to the leaching effects of rain and a portion of their undesirable components found in ashes csn pollute both ground and surface water[2]. Consequently, additional environmental problems will emerge.

The objectives of this study are to measure the elemental content of coal and CCPs, to determine the concentration level of heavy metals in CCPs leachate through TCLP, and to analyze the correlation between elemental content of coal and concentration of CCPsand leachate concentration of CCPs by TCLP.

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2. METHODOLOGY

Samples of coal, fly ash, bottom ash and coal ash were obtained from nine coal power plants in Indonesia. Coal ash is a mixture of fly ash and bottom ash. The type and code the samples are shown in Table 1. A direct acid digestion method using a microwave reaction system was carried out to determine heavy metal content. About 0.5 gram of dry fly ash, bottom ash and coal ash was selected from the composite samples and weighed. Further, 0.1 gram of coal was used for this step. The sample was digested with 2.5 ml of HNO_3 (nitric acid) and 7.5 ml of chloric acid (HCl). The digested material was then filtered and diluted to 50 ml with distilled water.

On the other side of the process, the TCLP procedure was based on EPA Method 1311 and SNI 19-6365-2000. Using this method, the CCPs samples were subjected to 18 ± 2 hour with the leaching solution. The leaching solution was a mixture of CH_3CH_2OOH (glacial acetic acid), reagent water and 1N NaOH (sodium hydroxide). The solution was diluted to a volume of 1 liter to have a pH of 4.93 ± 0.05. Then, the extract samples were analyzed by an ICPS-8100 Sequential Plasma Spectrometer to determine the level of heavy metal content[3].

3. RESULTS AND DISCUSSION

3.1 Element content of coal

The element content of coal is shown in Table 2. On average, the dominant element content

Table 1. Type and code of research samples.

Power Plant	Ombilin		Tanjung Enim		Tanjung Jati Unit 1			Tanjung Jati Unit 2			Tanjung Jati Unit 3			Tanjung Jati Unit 4			Rembang			Paiton I			Paiton 9		
Type of Sample	Coal	Coal Ash	Coal	Coal Ash	Coal	Fly Ash	Bottom Ash	Coal	Fly Ash	Bottom Ash	Coal	Fly Ash	Bottom Ash	Coal	Fly Ash	Bottom Ash	Coal	Fly Ash	Bottom Ash	Coal	Fly Ash	Bottom Ash	Coal	Fly Ash	Bottom Ash
Sample Code	CA	CaA	CB	CaB	CC	FC	BC	CD	FD	BD	CE	FE	BE	CF	FF	BF	CG	FG	BG	CH	FH	BH	CI	FI	BI

on the initial coal was boron. The average content of boron was 87 mg/kg, followed by barium (64.4 mg/kg). Meanwhile, the average content of cadmium (0.8 mg/kg) was the lowest of all the others. In terms of coal rank type, the means of element content on sub-bituminous and lignite was not found to be different.

Table 2. Element content of heavy metal in coal sample (mg/kg).

Sample Code	Ba	Cr	Co	Ni	Cu	Zn	Cd	B	Pb
CA	46.0	9.25	4.66	8.81	12.6	25.6	1.18	41.2	65.2
CB	50.5	2.10	2.76	2.36	3.0	15.4	0.47	151	13.6
CC	120	12.6	4.75	9.39	5.38	16.5	1.22	175	43.8
CD	59.2	5.46	3.16	6.08	2.88	15.0	0.62	94.7	11.7
CE	72.4	6.94	2.65	5.75	4.39	38.1	0.72	101	10.6
CF	79.1	9.65	3.28	7.09	4.08	44.0	0.89	94.9	13.8
CG	62.5	2.74	3.69	5.40	2.28	11.3	0.74	62.4	6.63
CH	37.6	0.67	2.07	2.93	1.48	2.67	0.39	32.1	2.13
CI	52.5	2.37	5.27	5.45	2.16	8.50	1.19	30.9	5.91
Average	64.4	5.75	3.59	5.92	4.25	19.6	0.82	87.0	19.3

The element content of the fly ash also shows a similar trend to the parent coal which was dominated by boron (967 mg/kg) and the smallest amount reached by cadmium (8.04 mg/kg). The element content for the bottom ash showed a different result for which the average content of barium was higher than the content of boron. However, the content of cadmium (27 mg/kg) was the smallest in number. The sequence of element content in coal ash was relatively similar to that in the initial coal. The characteristics of the coal had a direct influence on the chemical and mineralogical composition of the CCPs[4].

3.2 Distribution of element content for fly ash and bottom ash

Figure 1 shows the distribution element content of barium in the fly Ash and bottom Ash. Five of the data were located above the line, while two data were located on the opposite side of the line. This data indicated that the element of barium tends to enrich the fly ash.

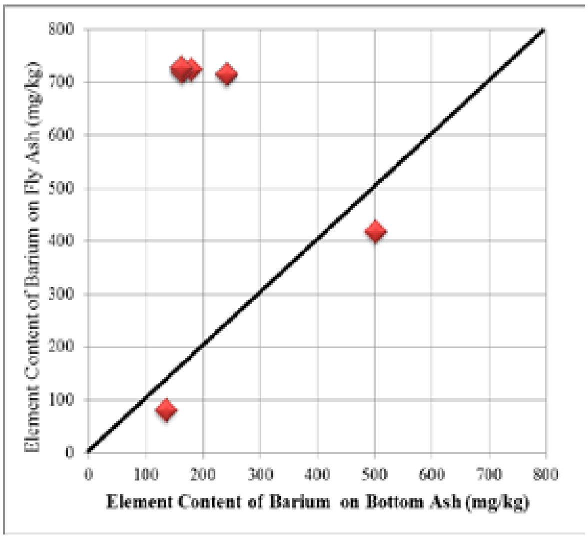

Fig.1. Distribution of element content of barium in the fly ash and bottom ash.

Figure 2 reveals the distribution of the element content of chromium in bottom ash and fly ash. It was clear that the position of all the data was above the line. That position means that the element of chromium tended to enrich the fly ash.

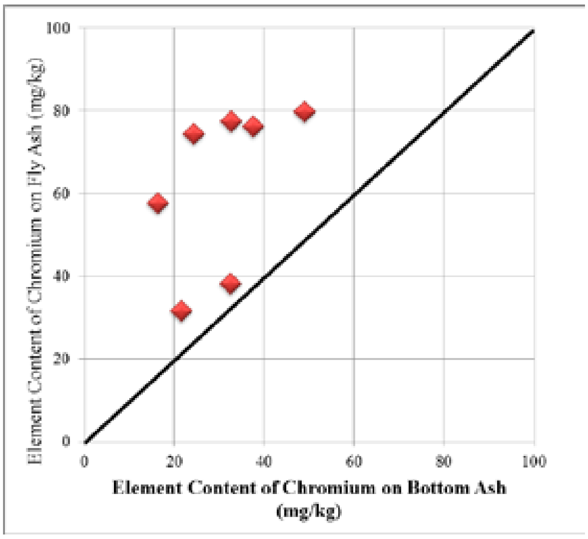

Fig.2. Distribution of element content of chromium in the fly ash and bottom ash

Figure 3 presents the distribution elemental content in bottom ash and fly ash for the cobalt element. For barium, the position of five data appeared on the upper side of the line while two data appeared under the line. Hence, it was clear that the element of cobalt tends to enrich the fly ash.

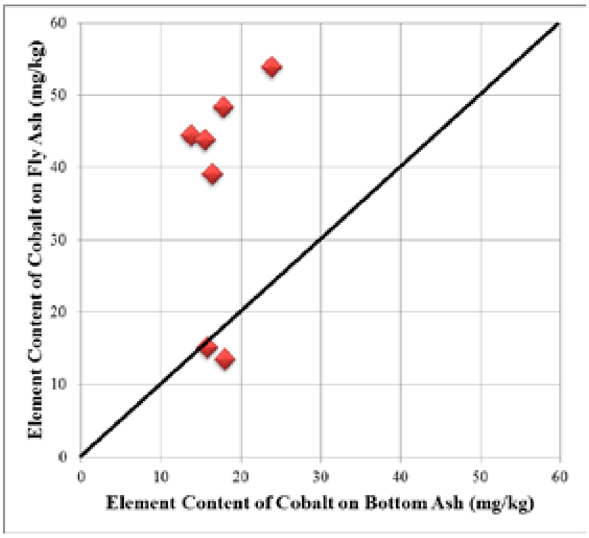

Fig.3. Distribution of element content of cobalt in the fly ash and bottom ash

Figure 4 shows the distribution element content of nickel in bottom ash and fly ash for nickel element. One piece of data was situated in line with the line, while the others were located above the line. To sum up, the element of nickel tends to enrich the fly ash

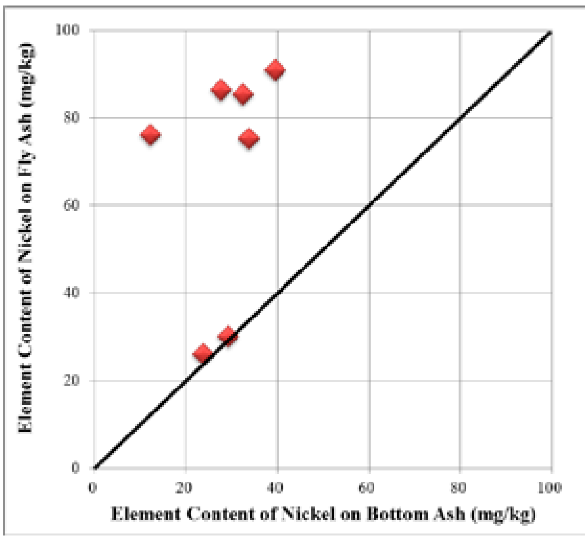

Fig.4. Distribution of element content of nickel in the fly ash and bottom ash

Figure 5 depicts the distribution element content in bottom ash and fly ash for copper element. The trend is similar to the distribution of barium where two of the data appeared under the line and the five others were located on the upper side of the line. Hence, on the figure, the element of copper tends to enrich the fly ash.

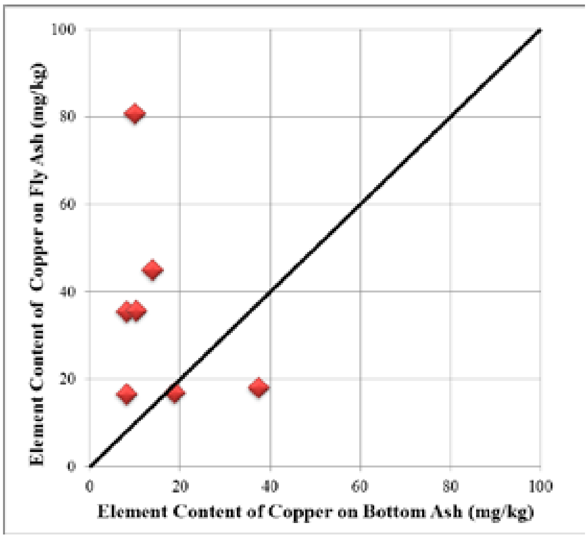

Fig.5. Distribution of element content of copper in the fly ash and bottom ash

Figure 6 depicts the distribution element content in bottom ash and fly ash for zinc. In this figure, the vast majority of the data is located above the line which can be interpreted as the element of zinc tends to enrich into the fly ash.

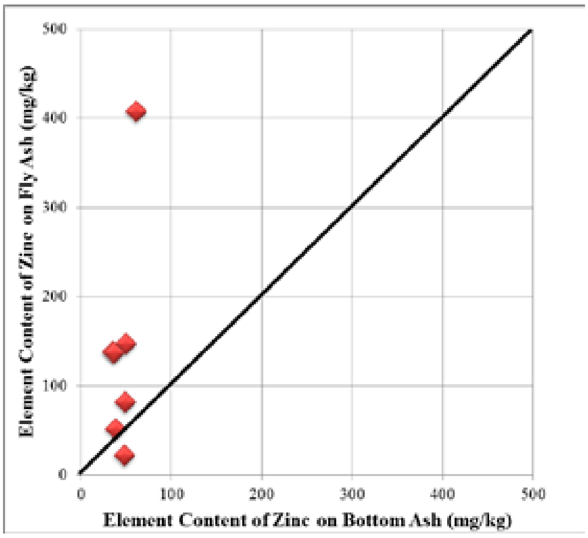

Fig.6. Distribution of element content of zinc in the fly ash and bottom ash

Figure 7 presents the distribution element content in bottom ash and fly ash of cadmium. The trend was the similarly to the trend for zinc element, that the majority the data was on the left side of the line and only one piece of the data was located on the right side of the line. Thus, the conclusion is the element of cadmium tends to enrich the fly ash

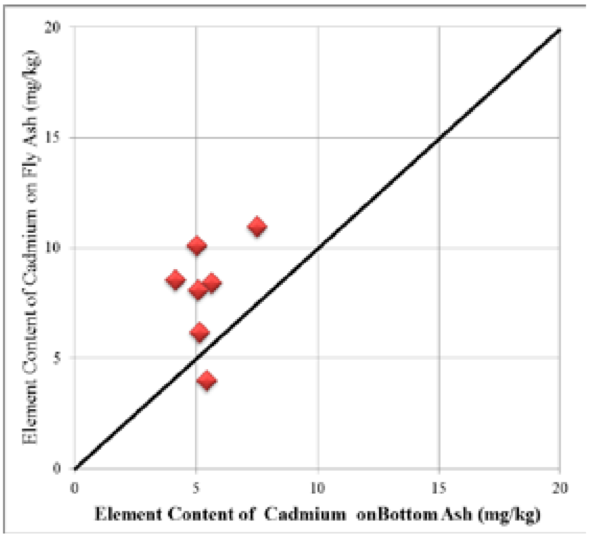

Fig.7. Distribution of element content of cadmium in the fly ash and bottom ash

Figure 8 reveals the distribution element content in bottom ash and fly ash for the boron element. There was one piece data located along the line but six were located on the upper side of the line. Generally, it was found that boron tends to enrich the fly ash.

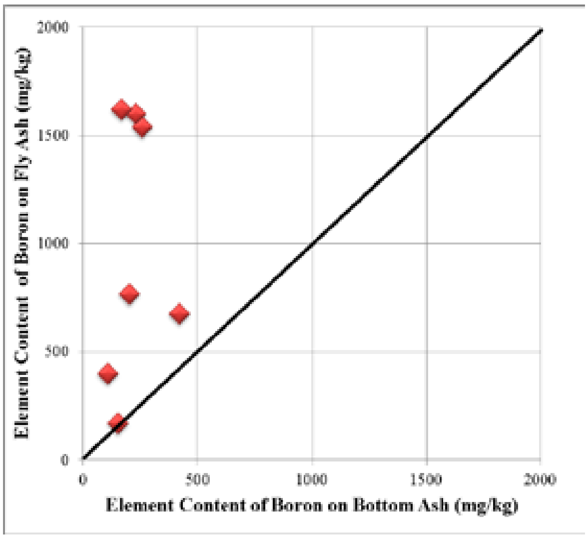

Fig.8. Distribution of element content of boron in the fly ash and bottom ash

Figure 9 depicts the distribution element content in bottom ash and fly ash for lead element. The trend resembled with the some elements, which the two data were located under the line. Thus, it can be interpreted that the the element of lead tend to enrich into fly ash.

Based on all the data, all of the elements tend to enrich the fly ash. Davison (1974) reported that the fine particle fraction of fly ash could be enriched into trace elements compared with the fraction of trace elements in the parent coal [5].

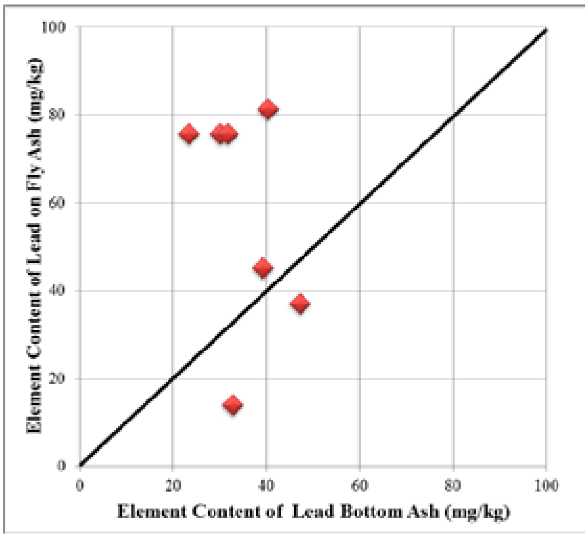

Fig.9. Distribution of element content of lead in the fly ash and bottom ash

This trend is caused by the volatilization of some elements in the boiler and their subsequent condensation in the cooler sections of the flue gas stream. Karayigit (2005) indicated that some of the volatile elements, notably As, Cd and Zn increase from a coarse to a finer particle size fly ash [6]. Similar observationwere seen for As, Cd, Pb and Zn as indicated by Hower (2001). Volatile elements like Zn and As will increase in concentration as a function of their decreasing particle size and consequently enhanced surface area of the fly ash. The content of volatile trace elements thus will increase with an increase in fly ash surface area [7].

3.3 Concentration for leachate (TCLP)

The concentration of heavy metals on fly ash leachates is shown in Table 3. On average, the concentration of boron (22.4 mg/L) was many times larger than the average of other elements which on average were under 1.0 mg/L. The fine particle fraction of fly ash were enriched in the trace elements compared with the fraction of trace elements in the parent coal [5].

The concentration of cadmium was not found in any of the seven fly ash leachates. Interestingly, the amount of Zn observed in the FI leachate (4.84 mg/L) was higher than for the other fly ash samples. Volatile elements such as Zn will increase in concentration as a function of decreasing particle size and consequently, also the enhanced surface area of the fly ash.

Table 3. Concentration of heavy metals on fly ash leachates (mg/L)

Sample Code	Ba	Cr	Co	Ni	Cu	Zn	Cd	B	Pb
FC	0.29	0.05	0.02	0.10	0.00	0.15	0.00	36.1	0.05
FD	0.20	0.04	0.02	0.11	0.00	0.14	0.00	37.4	0.05
FE	0.60	0.03	0.01	0.05	0.00	0.06	0.00	28.9	0.04
FF	0.75	0.00	0.00	0.03	0.00	0.04	0.00	20.4	0.02
FG	0.36	0.00	0.00	0.01	0.02	0.04	0.00	0.75	0.00
FH	0.37	0.08	0.00	0.03	0.00	0.00	0.00	20.7	0.03
FI	0.29	0.02	0.04	0.10	0.00	4.84	0.00	12.6	0.02
Average	0.41	0.03	0.01	0.06	0.00	0.75	0.00	22.4	0.03
Standard Limit	100	5.00	0.50	1.00	10.0	100	1.00	500	5.00

The result of heavy metals concentration on bottom ash leachates is shown in Table 4. Generally, the concentration level of heavy metals on bottom ash leachate was the much lower standard limit. The concentration of boron on bottom ash leachate also dominated and copper was the lowest concentration on the fly ash leachate. However, the concentration of boron on bottom ash was less than the concentration on the fly ash. The concentration of boron on the bottom ash leachate was considerably lower than the concentration of boron on the fly ash.

Table 4. Concentration of heavy metals on bottom ash leachates (mg/L)

Sample Code	Ba	Cr	Co	Ni	Cu	Zn	Cd	B	Pb
BC	0.17	0.02	0.03	0.04	0.02	0.11	0.02	1.86	0.04
BD	0.24	0.03	0.05	0.06	0.03	0.08	0.04	1.79	0.07
BE	0.46	0.04	0.03	0.06	0.03	0.23	0.04	1.78	0.04
BF	0.47	0.03	0.03	0.06	0.02	0.07	0.04	1.35	0.03
BG	0.37	0.03	0.03	0.06	0.02	0.10	0.04	0.70	0.02
BH	0.46	0.06	0.04	0.06	0.02	0.06	0.04	1.74	0.06
BI	0.52	0.04	0.04	0.05	0.04	0.04	0.04	0.62	0.13
Average	0.38	0.04	0.04	0.06	0.03	0.10	0.04	1.41	0.06
Standard Limit	100	5.00	0.50	1.00	10.0	100	1.00	500	5.00

The concentration level of heavy metals for the coal ash leachates is shown in Table 5. It can be seen that the concentration level from two power plants were lower and under standard limit. These concentrations for most heavy metals were under 1 mg/L except for boron (8.51 mg/L). In conclusion, the concentration level of heavy metals on CCPs were far below standard threshold.

Table 5. Concentration of heavy metals on coal ash leachates (mg/L)

Sample Code	Ba	Cr	Co	Ni	Cu	Zn	Cd	B	Pb
Ca A	0.30	0.05	0.04	0.06	0.06	0.10	0.04	3.38	0.10
CaB	0.77	0.04	0.03	0.04	0.04	0.05	0.03	13.6	0.08
Average	0.53	0.05	0.04	0.05	0.05	0.08	0.03	8.51	0.09
Standard Limit	100	5.00	0.50	1.00	10.0	100	1.00	500	5.00

3.4 Pearson correlation analysis

Table 6 shows the Pearson correlation matrix for the result content of coal, fly ash, and bottom ash, based on the accumulation of element content in every power plant. In general, it was clear that there were no correlations of elemental content on coal, fly ash and bottom ash, as evidenced by the significant correlation (*p*) result of fly ash and bottom ash, which revealed more than 0.05. The range of significant (2-tailed) was 0.110 to 1.00. The level all of those elements was far above the level of *p*, which means that there was no relationship between the element content of the coal to the element content of the fly ash or bottom ash

Table 6. Pearson correlation between the element content of coal and the CCPs for each elements (n=7)

	Ba		Cr		Co	
	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash
Pearson Correlation	-0.05	0.07	0.28	0.10	0.08	-0.30
Sig. (2-tailed)	0.92	0.88	.54	.84	.87	.51
	Ni		Cu		Zn	
	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash
Pearson Correlation	0.02	-0.003	.496	-.268	-0.31	-0.65
Sig. (2-tailed)	.97	.996	.258	.561	.50	.11
	Cd		B		Pb	
	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash
Pearson Correlation	-0.003	-0.48	.655	.487	.325	-.368
Sig. (2-tailed)	.996	.274	.110	.268	.477	.417

To identify the importance of effect size, the Pearson correlation on fly ash and bottom ash were r (7): 0.00 – 0.655, -0.001 – 0.485 respectively. These Pearson correlation results mostly could be categorized as weak correlation due to the number being less than 0.5[8]. Still, because there was no correlation on variables, this number was meaningless.

The result of Pearson correlation for the element content in coal and leachate concentration CCPs by TCLP is shown in Table 7. The significant correlation result for the variables on fly ash reveals a range of 0.120 to 0.84 and the significant correlation on the bottom ash was 0.01 to 0.809. The level of p was determined under 5 % ($p < 0.05$). Thus, there was no correlation for the majority of the elements

However, for the nickel and copper elements, there was correlation due to $p < 0.05$. The results of p for the nickel and copper were 0.01 and 0.03, respectively. Moreover, the Pearson correlation result for nickel and copper was -0.881 and -0.80, respectively, thus categorized as a very strong correlation between variable which means that when there is an increase in the number of concentrations of leachate in coal, the effect will be at the decreasing concentration for the CCPs leachate.

Table 7. Pearson correlation for element content of coal and the leachate concentration of CCPs by TCLP (n=7)

	Ba		Cr		Co	
	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash
Pearson Correlation	0.09	-0.63	-0.17	-0.80*	0.38	-0.24
Sig. (2-tailed)	0.84	0.13	.71	.03	.40	.60
	Ni		Cu		Zn	
	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash
Pearson Correlation	0.42	-0.881*	-.047	-.113	-0.28	0.52
Sig. (2-tailed)	.36	.01	.286	.809	.54	.23
	Cd		B		Pb	
	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash
Pearson Correlation	a	a	.643	.550	.519	-.276
Sig. (2-tailed)			.120	.201	.233	.549

** : correlation significant at the 0.05 level (2-tailed)*
a : cannot be computed because at least one of the variable is constant

4. CONCLUSIONS

Based on on the results of the study and the findings obtained from the laboratory tests, the following can be concluded:

a. The chemical characteristics of Indonesia's coal are dominated by boron, and cadmium makes up only little of that content.
b. The concentration level of CCPs leachates from nine power plants were far below the standard limit and the CCPs leachates can thus be categorized as non-hazardous material.
c. The majority of the elements did not have any correlation in terms of the element content of coal and the concentration of CCPs leachates except for nickel and copper.
d. The recommendations suggest that the government should be concerned with the regulation of CCPs leaching analysis report periodically, at least once every 6 months, for every power plant. It is necessary to assess the concentrations of other heavy metals such as arsenic, mangan and selenium on the CCPs leachate and further, conduct long-term studies on the characteristics and leaching behavior of heavy metal leachates and their effects on the environment.

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