Analysis and risk assessment of natural radioactivity elements in coal wastes from Medan industrial area

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Abstract. The Analysis of Natural Radioactivity content in coal wastes from Medan Industrial Area has been carried out by using Gamma Spectrometer with HP-Germanium detector. Coal wastes was collected from a pile of wastes in a plant which used two different origin of coal was Palembang and Kalimantan areas. The aim of this study to determine the content of activity concentration of natural radioactivity elements and to assess risk exposure to human and environment. The results of quantitative analysis of the activity concentration of natural radioactive elements from Palembang coal wastes of U-238, Th-232 and K-40 were 3640.60±593.70; 112.78±13.14 and 155.82±32.18 Bq/kg, respectively. Whereas for Kalimantan coal wastes the concentration of U-238, Th-232 and K-40 were 1778.77±79.29; 52.00±2.27 and 160.10±5.92 Bq/kg, respectively. Risk assesment of the exposure to radiation gamma of the wastes to human and environment in the vicinity of area, was calculated as risk indeces. The average radium equivalent (Ra eq) was of 2760.4168 Bq/kg, the average of absorbed dose rate (D) was of 1275.0414 nGy/h, gamma index (γi) was of 64.3468 and the average of annual effective dose was of 10.9022 mSv. All indeces were above average world values and therefore its suggested to suspend the use of the coal and the wastes. This was the preliminary study to measure the activity concentration of natural radioactivity in the study area.

1. Introduction
The use of coal to generate electricity in Medan Industrial area was began since the price of oil was high. Coal wastes contains natural radioactive elements. Thus the use of coal waste will produce the emission of radioactive elements which are Uranium, Thorium and Potassium [1]. Therefore, the wastes are significant sources of exposure to the natural radioactive elements which could effect the health of workers and population in the vicinity of industrial area. Since the use of coal as fossil energy is relatively new in the area. It seems no studies has been reported to assess the activity concentration of natural radioactive elements and dose risk assessment. This study was aimed to measure the activity of natural radioactive elements by using Gamma Spectrometry with a HP Germanium detector and then to assess the dose risk of radioactivity by associated with population and environment [3]. The coal origin was found in two different area, that was Kalimantan and Palembang areas. This study was proposed to alert the workers and public as well as goverment to the risk of the wastes and to take the precaution of choosing the origin of coal to be used and also how to dispose the waste safely.
2. Materials and Methods

2.1. Sample Preparation

Samples were taken from a heap of coal waste in a plant area. Two different origin of coal was used to generate the electricity was obtained from Palembang area and Kalimantan area. The samples were air dried under sunshine and then sieved with 200 micron mesh size and then samples were put into Marenellie beaker and sealed with adhesive and then samples were stored for 30 days to achieve secular equilibrium. The sample were weight again before Gamma Spectrometric measurement.

2.2. Analysis of Natural radioactivity

1. Measurements

A Gamma spectrometer with a HPGe detector from ORTEC (GEMF5390-XLB-C) interfaced with Data aquisition system Multi Channel Analyzer (MCA) coupled with spectral analysis was carried out with Gemo-200 software program.

The peak efficiency of the detector was determined using standard sources of 133Ba (356.1 keV), 137Cs (661.9 keV) and 60Co (1173.2 and 133.2 keV). U-238 activity concentration was estimated from 1001,03 keV, Ra-226 concentration was estimated from 609.31 keV and Th-232 concentration was estimated from 911.1 keV and K-40 was estimated from K-40 energy itself of 1460 keV.

The concentration of natural radioactivity of U-238, Th-232 and K-40 were obtained from the formula :

\[
C_{\text{avg}} = \frac{N_{SP} - N_{BG}}{E_{\gamma} \cdot P_{\gamma} \cdot W_{SP}}
\]  

Where \( C_{\text{avg}} \) is net counts of a sample peak at energy of E. \( N_{BG} \) is net counts of a background peak at energy of E and \( E_{\gamma} \) is the counting efficiency of the detector at energy (E), \( P_{\gamma} \) is the probability of Gamma Ray (Gamma yield of every E) and \( W_{SP} \) is the mass of samples (kg).

2. Risk Assessment

To assess the radiation risk due to coal wastes production to workers and public in the vicinity of industrial area the following radiation risk indices were used.

Radium Equivalent (Ra_{eq})

Since the concentration of natural radioactivity in samples is not uniform containing different amounts of radioactivity to uniformity with respect to exposure to radiation therefore Radium equivalent activity (Ra_{eq}) in Bq/kg has been defined through the following expression.

\[
Ra_{eq} = A_{U} + 1.43 A_{Th} + 0.771 A_{K}
\]  

Where \( A_{U} \), \( A_{Th} \) and \( A_{K} \) are the activity concentration of U-238, Th-232 and K-40. The maximum value of \( Ra_{eq} \) is below than 370 Bq/kg and above Indonesian Goverment Laws [5].

Gamma Radiation Risk Index (I_{G})

The risk of \( \gamma \) radiation index is a representative level index which is defined as radiation from natural radioactivity in building materials [4] in this study the wastes :

\[
I_{G} = A_{U}/300 + A_{Th}/300 + A_{K}/300
\]  

The index can be used for estimating of the level of radiation risk due to coal waste. Index value of \( I \leq 1 \) correspond to \( \leq 0.3 \) mSv/y, while \( I \leq 3 \) correspond to \( \leq 1 \) mSv/y.

According to this criterion materials with \( I \geq 3 \) should be avoided because these values correspond to dose rates exceed the limit of 1mSv/y of dose rate in air recommended for population [1]. Therefore,
where non dimensional and value of activity index does not exceed unity the material $A_{238}$, $A_{232}$ and $A_{40}$ can be used without restriction [8].

3. Absorbed Dose and Annual Effective Dose

Absorbed dose rate at 1 m above the ground has been estimated from the respective specific activities $A_{238}$, $A_{232}$ and $A_{40}$ using conversion factors in the expression below [8]

$$D \text{ (nGy/h)} = 0.462 A_U + 0.604 A_{Th} + 0.0417 A_K \quad (4)$$

To calculate annual effective dose for materials is used for floor, ceiling, and walls, it is used the next expression

$$D_{an\text{ out}} = \text{absorbed dose nGy-h x 0.2 x 0.75 SvGy}^{-1} x 10^{-6} \quad (5)$$

In the above expression the annual dose estimated by using conversion factor of 0.7 SvGy$^{-1}$ [7].

3. Results and Discussion
3.1. Activity Concentration of Natural Radioactivity

The results of measurement of activity concentration of U-238, Th-232 and K-40 in the coal wastes was given in Table 1.

| Sample       | Origin of Coal | Activity concentration of Natural Radioactivity (Bq/kg) |
|--------------|----------------|--------------------------------------------------------|
|              |                | U-238        | Th-232        | K-40          |
| Coal Waste   | Palembang      | 36460.60±593.7 | 112.7765±13.1367 | 155.8248±32.1795 |
| Coal Waste   | Kalimantan     | 1778.766±79.2950 | 52.0005±2.2655  | 160.6031±5.4243 |

The activity concentration of U-238 was very high for Palembang coal wastes of 36460.6 Bq/kg and Kalimantan coal wastes was lower than Palembang coal wastes of 1778.766±79.295 Bq/kg. However these values were much higher than world average value of 35 Bq/kg [8] and hence the use of this coal should be replaced with other coal which has lower radioactivity content. It should be mentioned that coal wastes studied in this area was fly ash wastes which has higher radioactivity content than coal [2].

The radioactivity content of Th-232 was of 112.7765±13.1367 Bq/kg and 52.005±2.2657 Bq/kg for Palembang and Kalimantan coal waste and those value were also higher than world average value of 40 Bq/kg [8]. However, the radioactivity content of K-40 was of 155.8248±32.1795 Bq/kg and 160.6031±5.9243 Bq/kg for Palembang and Kalimantan coal waste were in world the average values of 370 Bq/kg.

Therefore the coal waste has to be handled and disposed with extrem precautions since the activity concentration of U-238 very high and also the activity concentration of Th-232 was above average value of 40 Bq/kg.

3.2. Risk Assessment

To evaluate risk assessment impact due to natural radioactivity containing in coal wastes the radium equivalent, absorbed dose, gamma index and annual effective dose were calculated by using the expression or formula described and summarized and given in Table 2.
Table 2 Radiation Risk Indeces of Coal Wastes

| Sample                | $R_{aeq}$ (Bq/kg) | Absorbed dose (nGyh$^{-1}$) | Gamma Index | Annual effective dose (mSv) |
|-----------------------|-------------------|------------------------------|-------------|-----------------------------|
| Kalimantan coal waste | 1865.647          | 859.8791                     | 6.2426      | 1.0546                      |
| Palembang coal waste  | 36633.869         | 16919.4121                   | 122.1516    | 20.7499                     |
| World limit           | 370               | 59nGyh$^{-1}$                | >6          | 1mSv$^{-1}$                 |

From Table 2 it was shown that all the risk indeces was above (world) average limit and hence the coal wastes in the study area was having risk dose expose to gamma emission due to natural radioactivity containing in coal. Therefore precautions to the workers and population should be taken and it was suggested to suspend the activity of natural radionuclides of coal to be use as fossil fuel and also suggested to use low concentration of natural radioactivity to protect radiation risk expose to workers and public and environment.

This study was the beginning of measurements of the natural radioactivity in Medan Industrial Area. And the next study will examine the content of natural radioactivity in used coal and it sources as well as its bottom ash wastes.

4. Conclusion

The gamma ray analysis of coal wastes samples taken from Medan Industrial area has been carried out and has shown that the content of the natural radioactivity have much more than average annual world values as well as risk indeces. It is therefore suggested to suspend the use of coal wastes and otherwise that the coal waste should be handled in extreme precaution and workers should be protected from the risk. It is also necessary to study the natural activity content of coal before use by plants in the area.

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