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Neutron Absorption Capabilities of Turkish Colemanite Minerals

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Abstract. In this study the colemanite minerals which can be found in Turkey are classified according to their contents of B_2O_3 and Ca, their radioactivity behaviors due to neutron radiation, their neutron shielding efficiencies and the effect of mineral thickness on neutron shielding efficiency. The investigation was carried out with colemanite, colemanite with clay, and colemanite with arsenic minerals from the regions of Bigadiç, Emet, and Kestelek. The colemanite minerals were analyzed without any pretreatment. After carrying out the XRD (X-Ray Diffraction) analysis of the minerals, their B_2O_3 and Ca contents were investigated. In addition, the XRF (X-Ray Florescence) analysis was made for quantitative determination. Furthermore, a Howitzer neutron permeability experiment was made. As a result, the maximum B_2O_3 content was found in Bigadiç Colemanite with clay and the maximum Ca content was found in Bigadiç Colemanite. Colemanite from the Kestelek region yielded the highest neutron radiation absorption value among the other minerals.

Keywords: colemanite, neutron radiation, neutron shielding, mineral thickness

1. Introduction

Nuclear technology has many advantages in electrical energy production, medical fields, industry, agriculture and every kind of scientific research. At the other hand the technology comes with several hazardous situations for living organisms including human body. Radiation is one of the hazardous situations for nuclear technology. Radiation shielding is necessary for the health of the human body. The materials are going to be used for this purpose should decrease the level of radiation. Boron plays an important role as a shielding and control material in nuclear technology because of its high thermal neutron absorption cross section (σ = 750 barn) and its low energy γ rays induced by neutron radiation. But the extraction of pure boron from its minerals is a relatively long and expensive process. On the other hand, fast neutrons must be slowed down first and be absorbed by the shielding material. For this purpose, hydrogen is the most suitable element for the deceleration of fast neutrons. These two major reasons make the utilization of pure hydrated boron minerals attractive, which will be used without any treatment as shielding purposes, in processes involving neutron radiation [1, 2].

Turkey, which produces nearly 72.2% of the world reserves, is the most important producer of boron ores. Colemanite mineral is the mostly known boron mineral. Its hardness is 4-4.5 mohr and specific gravity is 2.42 g/cm^3. In Turkey it is found in the regions of Emet, Bigadiç and Kestelek also it is found in the USA. [3-5].

Countries, especially USA and France, use boron compounds as a shield material in nuclear reactor technologies. In the area of nuclear shielding, Buiyan and Ahmed, (1989), produced a shielding material named poly-boron in India, by adding boron to a polyethylene matrix. Gwaily et al., (2002), produced a thermal neutron radiation shield by using boron carbide and natural rubber. A neutron filter was made by Adib and Kilany (2003), using Bismut. Singh et al., (2004), produced a neutron shield material that is made up of PbO–B_2O_3 and Bi_2O_3–PbO–B_2O_3. Sakuraia et al., (2004), added various ratios of LiF and B_4C to a polymer matrix, producing a shielding material. Ersez et al., (2006), declared that a layer made of 96% Pb

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and 4% Sb with a thickness of 120 mm, which is mounted over a concrete layer, would keep the radiation within security limits. A ceramic shield material for neutron scattering equipments was developed by Cellia et al., (2006), which contains boron carbide. A phenol based neutron shield material that contains 6% boron, which is resistant to temperatures as high as 300^{o}C, was developed by Morioka et al., (2007). Chichester and Blackburn (2007), declared that bizmuth or lead alone are insufficient as biological shielding materials; that when bismuth is added in a polyethylene matrix or concrete, better results can be obtained. Some of the experiments done in Turkey in the area of adding boron minerals, mainly colemanite by Elbeyli et al., (2003), to a concrete but as it can be seen, materials like boron carbide, boron oxide, iron, lead and bismuth are used in shielding studies. However, the usage of boron minerals as a raw material cannot present [6-15].

The aim of this study is to analyse the colemanite mineral that can be used with the purpose of nuclear radiation absorption as a shield material, by examining their boron oxide, calcium and other element contents.

2. Experimental

2.1. Preparation and Determination of the Minerals using X-Ray Differactometer (XRD)

Colemanite minerals are supplied from the regions of Bigadiç, Emet and Kestelek, colemanite with clay minerals are supplied from the region of Bigadiç and colemanite with arsenic are supplied from the region of Emet.

All minerals were crushed, grinded and sieved at a mesh size of less than 140 microns. Then prepared minerals are subjected to the X-Ray Diffraction analysis by Philips PANanalytical X-Ray Differactometer.

2.2. Determination of the B_2O_3 Contents

Due to the interaction principle of the boron minerals with the thermal neutrons, the neutron shielding is made with the boron minerals. For this reason, the B_2O_3 amounts of the boron minerals should be known. With this aim, the B_2O_3 contents of the minerals are determined experimentally by Titration.

2.3. Determination of the Ca Contents

Similar to the B_2O_3 analysis, Ca contents are analysed experimentally with EDTA titration.

2.4. Determination of the Fe, Zn and Ar Contents

X-ray florescence spectrometer is a diverse method that can easily be used for elemental analysis. For the measurements, a silicon drift detector in a Minipal4 model instrument of PANalytical brand is used. The separation power of the silicon detector is between 4 kV-30kV.

2.5. Neutron Permeability Experiments

The neutron permeability experiments in Howitzer were carried out at room temperature between 18 – 22^{o}C with a thermal flux of approximately 10^4 n/cm^{2}s. In these experiments, the source detector space was kept constant at 5 cm and no space was left between the pellets and the detector. The scheme of the experiment is shown in Figure 1.

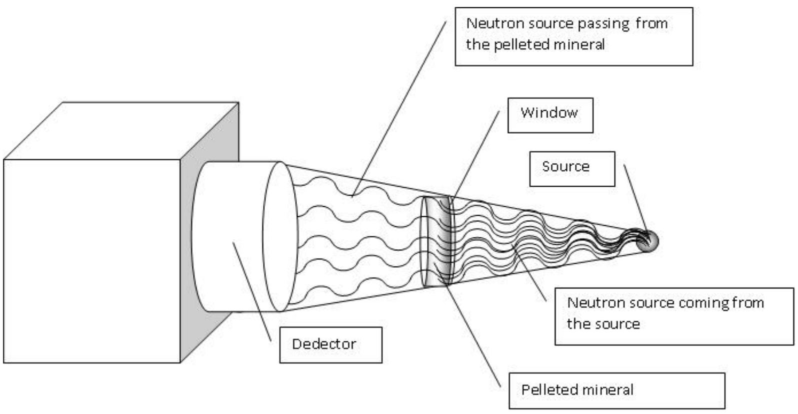

Fig. 1: Schematic shown of the neutron radiation through the pelleted mineral.

Neutron permeability is given as I/I_0 where "I" represents the neutron counts passing from the pelleted mineral and "I_0" represents the neutron counts passing the same way without meeting any minerals. The setup scheme of the experiment is shown in Figure 1. Two and three different pellet thicknesses (d) are selected for a better prediction.

3. Results and Discussions

3.1. XRD Results

In the identification analyses of colemanite minerals taken from different regions, the powder diffraction file (pdf) numbers, the names and the formulas are given in Table 1 according to their patterns.

Table 1: XRD Results of the Colemanite Minerals

Region	Boron Mineral	Pdf No	Mineral Name
Bigadiç	Colemanite	01-074-2336	Colemanite
	Colemanite with clay	01-082-1825	Colemanite
Emet	Colemanite	01-082-1825	Colemanite
	Colemanite with arsenic	01-082-1825	Colemanite
Kestelek	Colemanite	01-074-2338	Colemanite

3.2. B_2O_3 Contents

The B_2O_3 amounts of the minerals are found to be varying between 48.71 % and 55.53 % by weight. As presented in Table 2, colemanite with clay mineral from the Bigadiç region has the highest boron oxide content of 55.53 ± 0.19 and colemanite minerals from the Emet region has the lowest boron oxide content of 48.86 ± 0.50.

Table 2: B_2O_3 Contents of the Colemanite Minerals

Region	Boron Mineral	B_2O_3 Content (%)
Bigadiç	Colemanite	52.54 ± 0.65
	Colemanite with clay	55.53 ± 0.19
Emet	Colemanite	48.86 ± 0.50
	Colemanite with arsenic	49.56 ± 0.79
Kestelek	Colemanite	48.71 ± 0.29

3.3. Ca Results

The calcium contents, which are given in Table 3, show that the colemanite minerals have much more Ca contents then the others. Bigadiç region colemanite mineral has the highest amount of Ca, followed by the same amount of, by Kestelek and Emet regions.

Table 3: Ca Contents of the Colemanite Minerals

Region	Boron Mineral	Ca Content (mg/mL)
Bigadiç	Colemanite	83.57
	Colemanite with clay	32.06
Emet	Colemanite	70.14
	Colemanite with arsenic	52.10
Kestelek	Colemanite	70.14

3.4. XRF Results

The main purpose of XRF analysis was to determine the radioactive trace elements in the ores, if any. The results are given in Table 4 and the investigations proved that there was no trace of such elements in the ores, which could be dangerous for neutron shields against neutron fluxes. The investigation showed that colemanite with arsenic from Emet was more radioactive than the other ores. On the other hand, as the ores that are used directly in neutron shields must not contain any arsenic, colemanite with arsenic minerals are not suitable for human health.

Table 4: XRF Analysis of the Colemanite Minerals

Region	Boron Mineral	Fe (ppm)	Zn (ppm)	As (ppm)
Bigadiç	Colemanite	105.80	-	-
	Colemanite with clay	-	-	-
Emet	Colemanite	1531.00	-	-
	Colemanite with arsenic	751.50	48.90	3328.20
Kestelek	Colemanite	151.00	80.00	-

3.5. Howitzer Neutron Absorption Results

For the Howitzer experiments at each thickness, 10 parallel experiments are conducted and the final permeability values are calculated from the average of these experiments. The results are given in Table 5. Neutron Absorption values are calculated using the neutron permeability values.

Table 5. Neutron Absorption Values of the Boron Minerals

Region	Boron Mineral	d (cm)	Neutron Absorption (%)
Bigadiç	Colemanite	0.456	16.24 ± 2.31
		1.190	10.95 ± 1.12
	Colemanite with Clay	0.470	10.31 ± 1.61
		1.160	10.95 ± 0.00
Emet	Colemanite with Arsenic	0.450	9.76 ± 1.31
		0.693	13.08 ± 5.39
	Colemanite	0.549	12.04 ± 1.91
		1.120	12.86 ± 0.51
Kestelek	Colemanite	0.483	14.12 ± 6.33
		0.712	14.07 ± 1.15
		1.160	17.25 ± 1.22

4. Conclusions

From the results obtained from this study, it can be stated that the use of colemanite minerals as a neutron shielding material is suitable. Since colemanite mineral from the region of Kestelek had the highest neutron radiation absorption value among the others, its use would yield a better performance. In all minerals, the neutron radiation value increases due to increasing pellet thickness that can easily be seen on Figure 2. Colemanite with arsenic mineral shows a better performance than Emet colemanite but due to the presence of arsenic; its use is not suitable for humans. The Bigadiç colemanite with clay mineral shows the worst neutron radiation absorption performance when compared with other minerals.

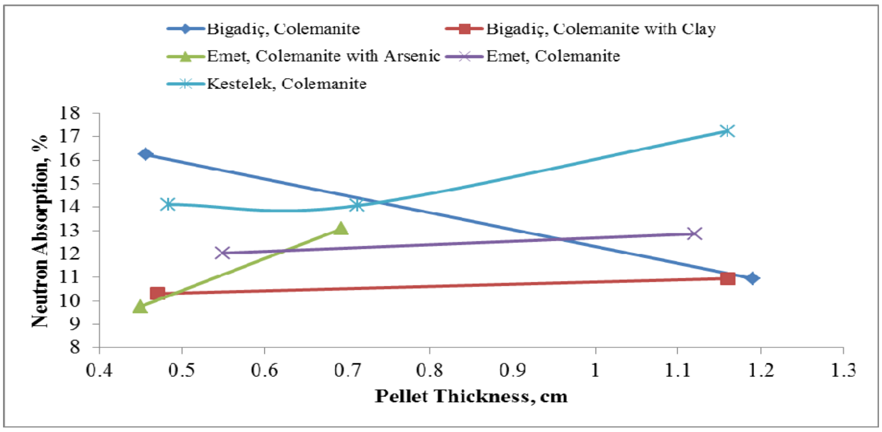

Figure 2. Neutron Absorption Value Comparison of the Colemanite Minerals

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