Physicochem. Probl. Miner. Process. 53(1), 2017, 184−191

www.minproc.pwr.wroc.pl/journal/

Physicochemical Problems of Mineral Processing

ISSN 1643-1049 (print)
ISSN 2084-4735 (online)

Received January 6, 2016; reviewed; accepted June 23, 2016

PHOTON ATTENUATION PROPERTIES OF CONCRETES CONTAINING MAGNETITE AND LIMONITE ORES

Aycan GUR*, Birol ARTIG, Tahir CAKIR*****

[*] Department of Physical Chemistry, Faculty of Science, Yuzuncu Yil University, 65080 Van, Turkey, aycangurbor@yahoo.com
[**] Department of Physics Faculty of Science, Yuzuncu Yil University, 65080 Van, Turkey
[***] Department of Radiation Oncology, Faculty of Medical, Yuzuncu Yil University, 65080 Van, Turkey

Abstract: In this study, gamma shielding properties of concretes containing magnetite and limonite ores at different ratios (5%, 10%, 15%, 20%, and 30%) were investigated by using a ^{60}Co (1.25 MeV) radioactive source which was built in Thratron 1000E™ device used for radiotherapy purposes. Then, the photon transmission values (I/I_0) were measured by 0.6 cm^3, farmer type, PTW™ ion chamber. The dose readings (I_0 and I), made by PTW™ Unidose Electrometer, were used to calculate the linear attenuation coefficient (μ, cm^{-1}), the mean free path (λ, cm), and the mass attenuation coefficient (μ_ρ, cm^2/g) by the Lambert equations, and the results were compared with the calculations obtained using the WinXCom computer program. The findings from this study revealed that the concretes containing magnetite and limonite ores were more effective than the ordinary concrete in the attenuation of gamma rays. It was determined that the values of the mean free path decreased with the increasing concentrations of magnetite and limonite ores while the linear attenuation coefficients for 10 concrete blocks increased with the increasing magnetite and limonite ore concentrations. A comparison of the theoretical values obtained from the WinXCom computer program and the experimental results revealed a good level of conformity.

***Keywords:** magnetite, limonite, cement, radiation shielding, WinXCom*

Introduction

During the twentieth century many other sources of radiation, mainly of an artificial nature, have come into existence to the development of technology such as X-ray machines, particle accelerators, and nuclear reactors. These developments have given rise to radioactive materials, and the number of people are exposed to nuclear radiation in a considerable increase. Today, the design and construction of radiation shielding to protect people from the harmful effects of radiation is one of the most important problems in nuclear engineering.

http://dx.doi.org/10.5277/ppmp170115

A radiation shield is a physical barrier placed between a radiation source and the object to be protected so as to reduce the radiation level at the position of the object. It is known that concrete is an effective, versatile, and economical material for the construction of radiation shielding. The shielding properties of concrete may be adapted to a wide range of uses by varying its composition and density. It possesses the properties required for the attenuation of both gamma and neutron radiation as well as having satisfactory mechanical and physical properties, reasonable cost, and low maintenance needs. A great number of scientific studies have been carried out on the radiation shielding of concrete containing different components such as building materials (Kharita et al., 2008, 2011; Medhat, 2009; Charanjeet et al., 2004; Bashter, 1997; El-Sayed Abdo et al.,2002), single elements (Murty et al., 2001; Murty and Devan, 2001), alloys (Akkurt et al., 2005; Angelona et al., 2001; El–Kateb et al., 2000; Icelli et al., 2005a,b; Murty et al., 2000), and also compounds (Bhandal and Singh, 1995; Khanna et al., 1996; Singh et al., 1996, 2003, 2005, 2010; Icelli et al., 2003, 2004, 2005 a,b; Shivaramu and Ramprasth, 2000; Icelli and Erzenoglu, 2004; Turgut et al, 2005; Baltas et al, 2007, Oto et al, 2012).

Linear attenuation coefficients (μ, cm^{-1}), mass attenuation coefficients (μ_ρ, cm^2/g), and mean free path values (λ, cm) are very important parameters for determining the penetration of gamma rays. Therefore, the photon attenuation characteristic of a material is represented in terms of μ, μ_ρ, and λ. In this study, the values of the linear attenuation coefficients and the mean free path (mfp) for the concretes containing magnetite and limonite ores at different quantities was determined experimentally, and calculated theoretically using the WinXCom program for gamma energy averages 1.25 MeV.

Experimental

Preparation of concrete

The magnetite and limonite ores used in this study were obtained from the Hun Export establishment in Elazig, Turkey. By keeping the constant ratio of water to cement as 0.5, three different groups of concretes (*K*, *M*, and L) were prepared for the tests in this study. The first group of concrete (*K*) was made by using only normal aggregate. The second one (*M*) was made by mixing magnetite ore instead of the normal aggregate in fractions of 5%, 10%, 15%, 20%, and 30% by weight in concrete, which were tagged as M_1, M_2, M_3, M_4, and M_5, respectively, and the third one (*L*) was made by mixing limonite ore instead of the normal aggregate in fractions of 5%, 10%, 15%, 20%, and 30% by weight in concrete, which were tagged as L_1, L_2, L_3, L_4, and L_5, respectively. A total of 11 different concrete samples were produced, and the concrete compositions are given in Table 1. The modular sand in Table 1 represents the total mass of the aggregate, and the magnetite or limonite ores added instead of aggregate at the ratios of 5%, 10%, 15%, 20%, and 30% by weight in concrete. The chemical compositions of the cement, magnetite and limonite ores were determined using the X-ray fluorescent method. The results are presented in Table 2.

Table 1. Concrete composition

Concrete Name	Magnetite Content (%)	Limonite Content (%)	Water (g)	Cement (g)	Modular Sand (g)
K	-	-	60	120	360
M_1	5	-	60	120	360
M_2	10	-	60	120	360
M_3	15	-	60	120	360
M_4	20	-	60	120	360
M_5	30	-	60	120	360
L_1	-	5	60	120	360
L_2	-	10	60	120	360
L_3	-	15	60	120	360
L_4	-	20	60	120	360
L_5	-	30	60	120	360

Table 2. Chemical composition of magnetite ore, limonite ore, and cement

Compounds	Magnetite (%)	Limonite (%)	Cement (%)
SiO_2	5.50	1.76	16.65
Al_2O_3	1.57	0.71	3.17
Fe_2O_3	73.64	86.52	3.41
CaO	12.98	4.55	62.03
MgO	0.95	0.78	1.36
SO_3	0.23	0.09	5.92
K_2O	0.02	0.03	0.87
Na_2O	4.55	5.40	6.17
SrO	-	-	0.41
P_2O_5	0.43	0.15	-
MnO	0.13	-	-

Apparatus and procedure

Cobalt-60 is almost solely used as the gamma radiation source for industrial use because of its easy production method (Gamma Irradiators for Radiation Processing, International Atomic Energy Agency Vienna, Austria). The concrete samples were irradiated with photons emitted from a ^{60}Co source having two gammas; the first one was 1.1732 MeV, and another one was 1.3325 MeV (Osmanlioglu, 2006). In this study, the average of these two energies was taken as 1.25 MeV because of having approximately the same emission probability and preferring specially for radiation stability in dose absorption studies (Yaltay et al., 2015). The photon transmission values I/I_o were measured using 0.6 cm^3, farmer type, PTW™ ion chamber. The schematic arrangement of the experimental setup used in the study is seen in Fig. 1. As shown in Fig. 1., firstly a 5×5 cm^2 collimator, and secondly lead with 1 cm^2 radius hole were used to obtain a narrow beam. I and I_0 readings were made simultaneously in the same ambiance for all the concrete samples. Firstly, a reading was made without sample as I_0 then next reading was made with the sample as I and linear attenuation coefficient (μ) and mean free path (λ) were calculated by the Lambert equation (Eq. 1):

$$I = I_0 e^{-\mu x} \quad (1)$$

where x is the material thickness (cm), I_0 is the incident gamma ray, I is the photon intensity recorded in detector, and μ is the linear attenuation coefficient (cm^{-1}). The experimental values of the linear attenuation coefficients and the mean free path were compared with the calculations obtained from the WinXCom computer program. The percentage of each compound in the concrete sample was determined in order to run the program, and 1.25 MeV energy photon setting was selected from the WinXCom program. Finally, the total mass attenuation coefficients μ_ρ (cm^2/g) were calculated (Gerward et al., 2001).

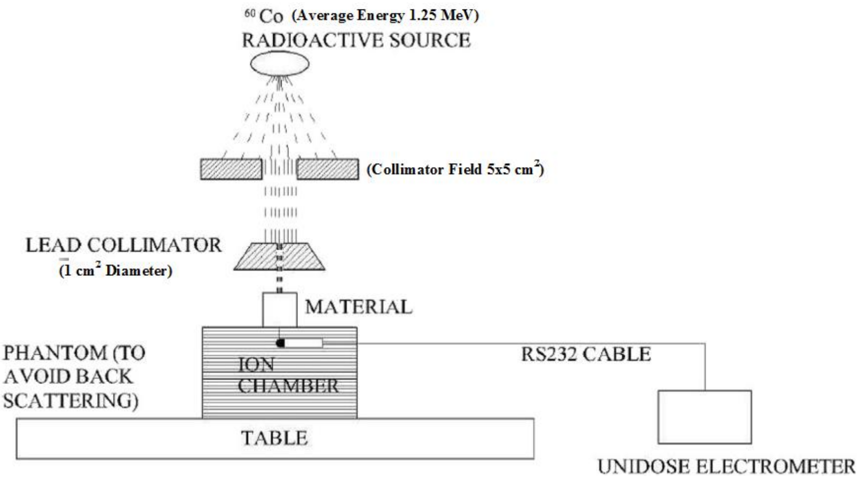

Fig. 1. Schematic view of the experimental system

Results and discussion

In the present study, the intensity of the incident (I_o) and transmitted (I) gamma rays were measured for three different groups of concrete samples containing normal aggregate, magnetite, and limonite ores at different quantities. Using Lambert's Law, the linear attenuation coefficients and the mean free path values were measured experimentally, and the mass attenuation coefficients were calculated theoretically using the WinXCom computer program for 1.25 MeV. The calculated and measured results, as presented in Table 3, identified a good level of conformity between the experimental and theoretical results.

Table 3. Theoretical and experimental values of linear attenuation coefficients and mean free path at 1.25 MeV

Concrete	1.25 MeV WinXCom μ (cm^{-1})	1.25 MeV WinXCom λ (cm)	1.25 MeV Experimental μ (cm^{-1})	1.25 MeV Experimental λ (cm)
K	0.1295	7.7221	0.1179 ± 0.0002	8.4832 ± 0.0169
M_1	0.1333	7.5032	0.1197 ± 0.0001	8.3531 ± 0.0052
M_2	0.1344	7.4394	0.1199 ± 0.0001	8.3375 ± 0.0104
M_3	0.1359	7.3585	0.1209 ± 0.0007	8.2691 ± 0.0448
M_4	0.1393	7.1775	0.1218 ± 0.0009	8.2100 ± 0.0602
M_5	0.1423	7.0299	0.1247 ± 0.0003	8.0163 ± 0.0221
L_1	0.1281	7.8047	0.1183 ± 0.0002	8.4522 ± 0.0131
L_2	0.1308	7.6477	0.1188 ± 0.0005	8.4156 ± 0.0340
L_3	0.1342	7.4524	0.1217 ± 0.0005	8.2162 ± 0.0355
L_4	0.1385	7.2197	0.1221 ± 0.0002	8.1899 ± 0.0126
L_5	0.1445	6.9192	0.1258 ± 0.0001	7.9484 ± 0.0048

The theoretical and experimental values of the linear attenuation coefficients versus concentration of magnetite and limonite ore in the concrete sample are plotted in Figs. 2 and 3, respectively. As shown in Figs. 2 and 3, both the linear attenuation coefficients for the concrete containing magnetite and limonite ores are higher than for the concrete containing normal aggregates. This can be attributed to the increasing ratios of magnetite and limonite ores.

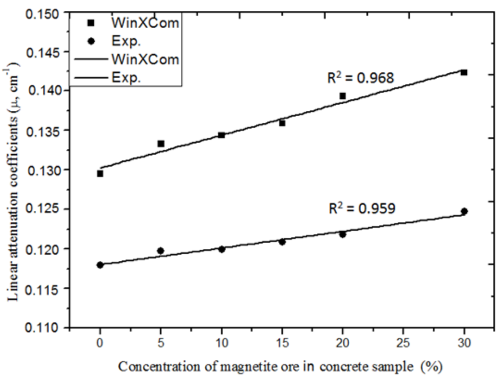

Fig. 2. Linear attenuation coefficient versus concentration of magnetite ore in the concrete samples

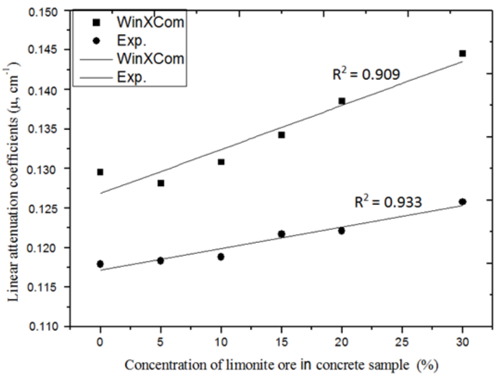

Fig. 3. Linear attenuation coefficient versus concentration of limonite ore in the concrete samples

Another important parameter in the radiation shielding is the mean free path being the average distance a gamma ray travels through the absorber before interacting. Figures 4 and 5 indicate how the mean free path value changes with changes in the concentrations of magnetite and limonite ores in the concrete samples. It can be seen from Figs. 4 and 5 that the mean free path values decrease with the increasing rates of magnetite and limonite ores, meaning that concretes containing magnetite and limonite ores provide better radiation shielding than ordinary shielding concretes.

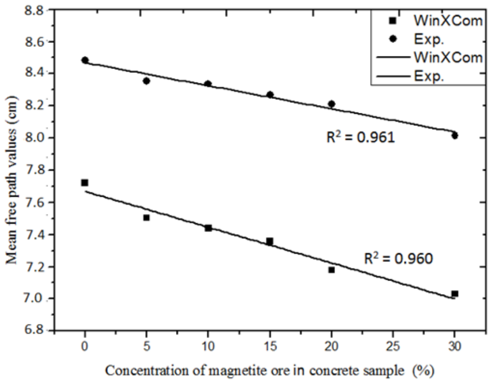

Fig. 4. Mean free path value versus concentration of magnetite ore in the concrete sample

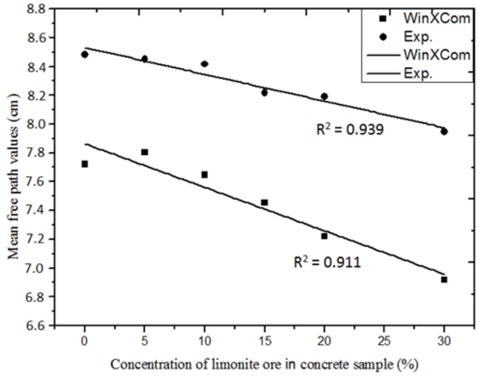

Fig. 5. Mean free path value versus concentration of limonite ore in the concrete sample

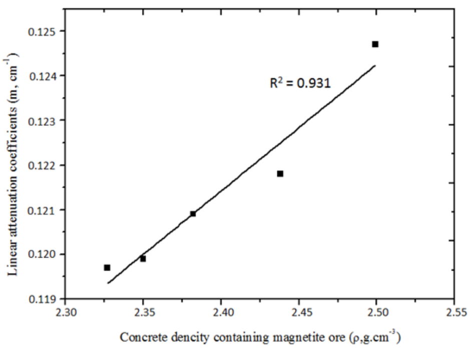

Fig. 6. Linear attenuation coefficient versus concrete density containing magnetite ore in the concrete sample

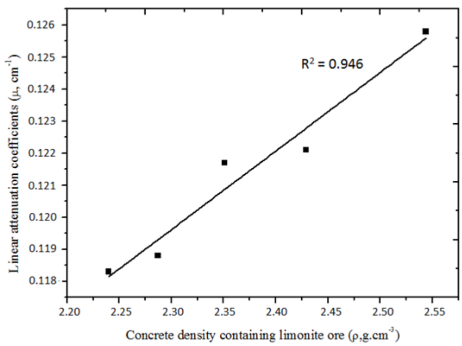

Fig. 6. Linear attenuation coefficient versus concrete density containing magnetite ore in the concrete sample

When magnetite and limonite ores were added, instead of normal aggregate, in a certain concentration to make concrete samples, the density of each concrete sample changed. The effect of the change in the form of density vs. linear attenuation coefficients was investigated, and the results are respectively presented for the concrete sample containing magnetite and limonite ores in Figs. 6 and 7. As seen from

Figs. 6 and 7, the increasing density of the concrete sample resulted in the increased linear attenuation coefficients.

Conclusions

In this study, we have investigated radiation transmission of concretes containing magnetite and limonite ore at the 1.25 MeV energy. It is concluded that the addition of magnetite and limonite ore in concrete is an alternative option that can be used for the purposes of gamma ray shielding.

Acknowledgement

This study has been supported by the Yuzuncu Yil University Foundation (2014-FBE-D102).

References

AKKURT I., BASYIGIT C., KILINCARSLAN S., MAVI B., 2005, *The shielding of γ-rays by concretes produced with barite*, Prog. Nucl. Energy, 46 (I), 1−11.

AKKURT I., AKYILDIRIM H., MAVI B., KILINCARSLAN S., BASYIGIT C., 2010, *Photon attenuation coefficients of concrete includes barite in different rate*, Ann. Nucl. Energy, 37, 910−914.

AKKURT I., AKYILDIRIM H., MAVI B., KILINCARSLAN S., BASYIGIT C., 2010, *Radiation shielding of concrete contaning zeolite*, Radiat. Measur., 45, 827−830.

ANGELONA M., ESPOSTITO A., CHITI M., GENTILE A., 2001, *Measurements of mass attenuation coefficients for four mixtures using X _ rays from 13 keV up to 40 keV*, Radiat. Phys. Chem., 61, 547−548.

BALTAS H., CELIK S., CEVIK U., YANMAZ E., 2007, *Measurement of mass attenuation coefficients and effective atomic numbers for* MgB_2 *superconductor using X – ray energies*, Radiat. Meas., 42, 55−60.

BASHTER I.I., 1997, *Calculation of radiation attenuation coefficients for shielding concretes*, Ann. Nucl. Energy, 24(17), 1389−1401.

BHANDAL G.S., SINGH K., 1995, *Total and partial mass attenuation coefficients and effective atomic number studies in different solid state nuclear track detectors*, Radiat. Phys. Chem., 47, 109−116.

CAKIR T., GUR A., ARASOGLU A., 2012, *The comparison of absorbed dose measurements for water and artificial body fluid*, Int. J. Radiat. Res., 10(3-4), 157−164.

DEMIR F., BUDAK G., SAHIN R., KARABULUT A., OLTULU M., SERIFOĞLU K., UN A., 2010, *Radiation transmission of heavyweight and normal-weight concretes containing colemanite for 6 MV and 18 MV X-rays using linear accelerator*, Ann. Nucl. Energy, 37, 339−344.

EL–KATEB A.H., RIZK R.A.M., ABDUL–KADER A.M., 2000, *Determination of atomic cross-sections and effective atomic numbers for some alloys*, Ann. Nucl. Energy, 27, 1333 −1343.

GERWARD L., GUILBERT N., BJORN JENSEN K., LEVRING H., 2001, *X- ray absorption in matter. Reeng. XCOM*, Radiat. Phys. Chem., 60, 23 − 24.

GERWARD L., GUILBERT N., BJORN JENSEN K., LEVRING H., 2004, *WinXCom – a program for calculating X- ray attenuation coefficients*, Radiat. Phys. Chem., 71, 653−654.

ICELLI O., ERZENOGLU S., GURBULAK B., 2005a, *Mass attenuation coefficients for ntype InSe InSe InSe:Gd InSe:Ho and InSe:Er single crystal,* J. Quant, Spectrosc. Radiat. Transf., 90, 399−407.

ICELLI O., ERZENOGLU S., KARAHAN I.H., CANKAYA G., 2005b, *Effective atomic numbers for CoCuNi alloys using transmission experiments*, J. Quant. Spectrosc. Radiat. Transf., 91, 485−491.

KHANNA A., BHATTI S.S., SINGH K.J., THIND K.S., 1996, *Gamma – ray attenuation coefficients in some heavy metal oxide borate glasses at 662 keV*, Nucl. Instrum. Methods Phys. Res. B, 114, 217−220.

KHARITA M.H., YOUSEF S., AINASSAR M., 2009, *The effect of carbon powder addition on the properties of hematite radiation shielding concrete*, Progr. Nucl. Energy, 51, 388−392.

MAKARIOUS A.S., BASHTER I.L., EL-SAYEDABDO A., SAMIR ABDEL AZIM M., KANSOUH W.A., 1996, *On the utilization of heavy concrete for radiation shielding*, Ann. Nucl. Energy, 23, 195−206.

MURTY V.R.K., DEVAN K.R.S., 2004, *Photon interaction cross section in the low energy region in Mg and V*, Radiat. Phys. Chem., 71, 671−672.

MURTY V.R.K., WINKOUN D.P., DEVAN K.R.S., 2000, *Effective atomic numbers for W/Cu alloy using transmission experiments*, Appl. Radiat. Isot., 53, 945−948.

MURTY V.R.K., WINKOUN D.P., DEVAN K.R.S., 2001, *Total photoelectric cross sections close to absorption edges*, Radiat. Phys. Chem., 51, 361−362.

OSMANLIOGLU A.E., 2006, *Management of spent sealed radioactive sources in Turkey*, Health Physics Society, 91, 258−262 .

OTO B., GUR A., 2013, *Determination of mass attenuation coefficients of concretes contaning ulexite and ulexite concentrator waste*, Ann. Nucl. Energ, 59, 72−74.

OTO B., GUR A., KACAL M.R., DOGAN B., ARASOGLU A., 2013, *Photon attenuation properties of some concretes contaning barite and colemanite in different rates*, Ann. Nucl. Energy, 51, 120−124.

OTO B., GUR A., 2012, *Determination of mass attenuation coefficients for concretes contaning tincal concentrator waste*, International Journal of Physical Sciences, 7(44), 5861−5864.

SINGH H., SINGH K., G., GERWARD L., NATHURAM R., LARK B.S., SAHOTA H.S., KHANNA A., 2003, *Barium and calcium borate glasses as shielding materials for x-rays and gamma-rays*, Phys. Chem. Glass, 44, 5−8.

SINGH S., GHUMMAN S.S., SINGH C., THIND K.S., MUDAHAR G.S., 2010, *Buildup of gamma ray photons in flyash concretes: a study*, Ann. Nucl. Energy, 37, 681−684.

TURGUT U., BUYUKKASAP E., SIMSEK O., ERTUGRUL M., 2005, *X–ray attenuation coefficients of Fe compounds in the K – edge region at different energies and the validity of the mixture rule*, J. Quant. Spectrosc. Radiat. Transf., 92, 143−151.

YALTAY N., EKINCI C.E., CAKIR T., OTO B., 2015, *Photon attenuation properties of concrete produced with pumice aggregate and colemanite addition in different rates and the effect of curing age to these properties*, Progress in Nuclear Energy, 78, 25−35.

YILMAZ E., BALTAS H., KIRIS E., USTABAS I., CEVIK U., EL-KHAYATT A.M., 2011, *Gamma ray and neutron shielding properties of some concrete materials*, Ann. Nucl. Energy, 38, 2204−2212.