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ROLE OF ORE MINERALOGY IN SELECTING BENEFICIATION ROUTE FOR MAGNESITE-DOLOMITE SEPARATION

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Abstract. Characterization and beneficiation of magnesite-dolomite sample were performed. The role of ore mineralogy in selecting the most adequate concentration method for magnesite-dolomite separation was found to be detrimental. The microscopic analysis showed that dolomite is stained with goethite and lepidocrocite (weakly magnetic minerals), while magnesite is stained with hematite and magnetite (highly magnetic mineral). A dry magnetic separation technique was used to separate dolomite from magnesite. The magnetic separation of the sample resulted in a magnesite concentrate product assaying 1.12% CaO with 46.02% recovery and CaO/SiO_2 molar ratio = 1.62. This magnesite product is suitable for basic refractory. Besides, middling fraction was produced, containing 44.63% magnesite and 10.95% dolomite. This product is suitable for making low-loss forsterite dielectrics.

Keywords: *magnetic separation, refractory materials*

Introduction

A vast development of heavy and light industries increased the demand for refractories, particularly basic refractory. The basic refractories e.g. magnesite, dolomite, forsterite and their derivatives present great importance for various industries (Girgis and Gag, 1970; Othman and Khalil, 2005). For the forsterite and forstertie-magnesite refractories, carbonate rock, rich in MgO, is considered as a suitable source of raw materials for forsterite brick-making. The presence of impurities, associated with the magnesite ores, reduces its refractoriness. Dolomite, which contains calcium, complicates technical processing during firing of magnesite. Thus, the CaO/SiO_2 molecular ratio is important in determining the quality of magnesite refractoriness, which should not exceed 2. This ratio could be obtained by removing a certain percentage of dolomite, which determines the CaO content, through beneficiation processes. Different methods for magnesite-dolomite separation

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have been applied (Chen and Daniel, 2005; Gonglan and Daniel, 2004; Wanzhong et al., 2011). The criteria for the selection of the most adequate concentration method include a series of parameters. The most important is related to ore mineralogy (Araujo et al.2003; Kumar et al. 2010; Upadhyay et al., 2009). There has been considerable interest in recent years in the development of automatic systems for the measurement of mineral composition and texture to solve mineral processing problems. The present work deals with the characterization and beneficiation of magnesite-dolomite ore. The aim was to obtain a magnesite product with a low CaO content to be suitable for refractory industries.

Experimental

Materials

A representative talc-carbonate sample was obtained from the Wadi El-Barramiya locality. It is situated in the Eastern Desert of Egypt and lies between longitudes 33° 44′ 00″–33° 49′ 00″ E and latitudes 25° 03′ 20″–25° 06′ 30″ N. The ore sample, supplied as blocks, was crushed in a 5x6 Denver jaw crusher followed by a "Wedag" rod mill in a closed circuit with a 0.25 mm sieve. The –0.25 mm fraction was passed on a 0.045 mm sieve. The –0.25+0.045 mm size fraction was used in this study. The sample was subjected to flotation using a frother at neutral pH to separate talc from the carbonate fraction (Yehia and Al-Wakeel, 2000). The present study was conducted on the carbonate fraction. Table 1 presents the chemical and mineral composition of the studied sample. It shows that the sample is composed mainly of two minerals, that is magnesite and dolomite. There are other three minerals found in subordinate amounts including talc, serpentine and quartz. The chemical composition of the sample indicates that it is composed mainly of three components: MgO, SiO_2 and Fe_2O_3. It has also relatively high amounts of CaO, which indicates the presence of dolomite.

Table 1. Mineral and chemical composition of the carbonate sample

Mineral composition, %					Chemical composition, %				
Talc	Magnesite	Dolomite	Serpentine	Quartz	SiO_2	MgO	CaO	Fe_2O_3	L.O.I.
2.84	73.58	17.58	1.56	4.89	9.86	33.92	5.73	7.18	40.48

L.O.I. = Loss on Ignition

Methods

Minerals association and characters as well as grain size were investigated by mineralogical examination of hand-picked samples. Identification of minerals by reflected light from polished sections was performed. The polished sections were examined under an "Ortholux Leitz" microscope.

The identification of the composition of the ore sample was possible by studying the X-ray patterns of the specimens using a Philips X-ray diffractometer (PW 1010).

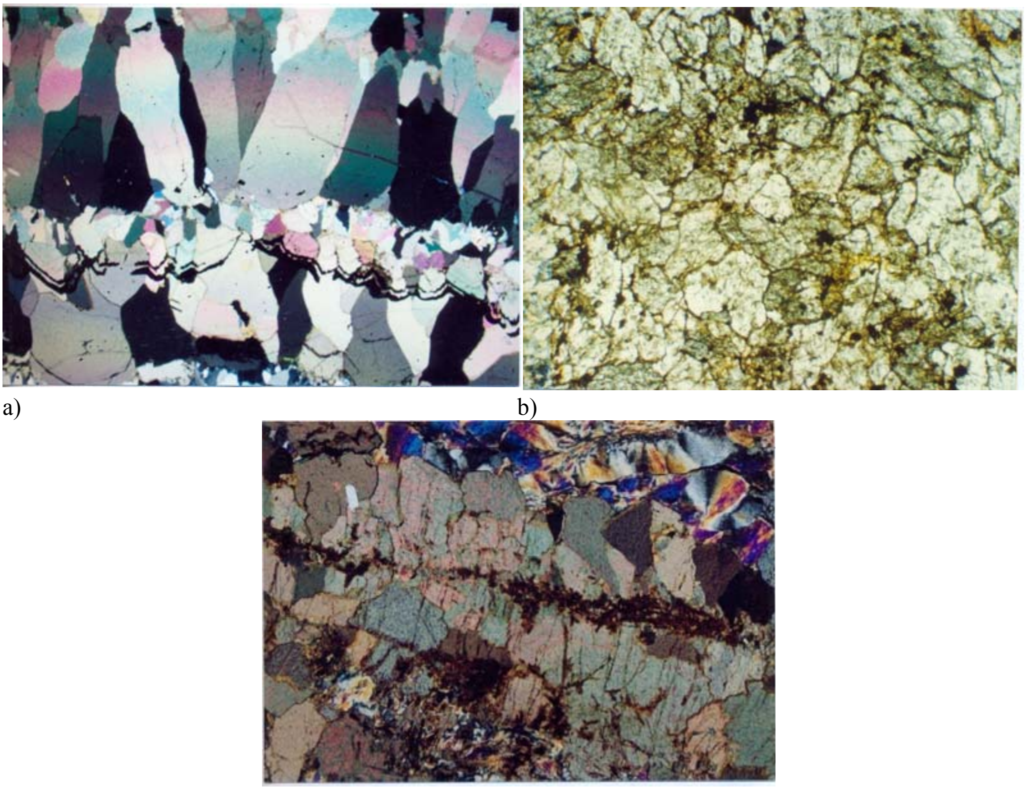
Mg, Ca and Fe were determined using Inductive Couple Plasma Emission Spectrometer. SiO_2 was determined gravimetrically. “Carpco” high intensity induced roll magnetic separator, model MIH (13) 111-5, was employed in this investigation as a free fall kind of separator. For efficient separation, the feed material should always be dry, free flowing and free from slimes. In this study, the controlling parameters such as the magnetic field strength and drum speed were modified in such a manner that the recovery-grade relationship could be plotted.

Results and discussion

Petrographic and geochemical analyses

The talc-carbonate rocks of Wadi El-Barramiya are well developed through the alteration of the serpentine rocks by carbon dioxide emanations. This rock is an alteration product of ultra basic rocks such as dunite which is composed of Fe and Mg bearing minerals (olivine and pyroxene). A microscopic examination indicated that magnesite was found in variable crystal sizes ranging from medium to very coarse reaching up to 2.45 mm (Fig. 1). Besides, dolomite occurs in the form of patches and veinlets of microcrystalline, rhombic, and zoned crystals. The carbonate ore shows a brownish tinge of iron-bearing minerals which can be a surface coating or disseminated grains in a matrix of carbonate. It is shown there that dolomite is stained with goethite (α-FeOOH) and lepidocrocite (γ-FeOOH) (weakly magnetic minerals) while magnesite is stained with hematite and magnetite (strongly magnetic mineral). This differential association was controlled by iron oxide precipitation (Kremenetskaya et al., 2009). The source of the iron in the studied ore sample was in the breakdown of ferromagnesium silicates where iron is present in a ferrous form (Ormo et al., 2004). It was suggested that carbonic acid (resulting from dissolving CO_2 gas in water) weathered the ferromagnesian minerals to form magnesium-iron-carbonate-rich solution. The released iron from the minerals is oxidized, when exposed to the surface, to form the red coloration of the “red beds”. The oxidized ferric iron is highly immobile. The iron needs to be reduced to Fe^{+2} (by donation of electrons) in order to be put into solution and transported.

Previous studies on iron mineralization in the carbonate ore suggested that iron is mobilized and removed by reducing water that moved along conduits (e.g. faults or fractures) and then outwards into adjacent permeable rocks (Beitler et al., 2003; Beitler, et al., 2003; Parry et al., 2004). The fluid is reducing possibly due to the presence of hydrocarbons, methane, organic acids or hydrogen sulfide. When the reducing water (acidic water), carrying iron(II), meets and mixes with shallow, oxygenated ground water (alkaline water), iron is precipitated to form a variety of iron oxides (Grosz et al., 2006). However, hydroxide ions formed from the dissolution of dolomite are almost completely bound to the ferric solution to form



a) b)

c)

Fig. 1. Carbonate minerals with iron oxyhydroxides. (a) different generations of dolomite crystals separated by goethite bands in its characteristic colloform structure, plane polarized, (b) magnesite with hematite on the crystal boundaries, crossed polar and (c) vein of coarse magnesite crystals stained and bounded by magnetite. Scale-shaped crystals and fine fibers of serpentine in the upper most part

dolomite are almost completely bound to the ferric solution to form hydroxocomplexes of iron. This means that the acidic fluid containing ferric oxides is neutralized on contact with dolomite. This results in goethite precipitation onto dolomite surface. Microscopic analysis of the magnesite-dolomite ore sample indicates that dolomite is stained with goethite while magnesite is stained with hematite and magnetite. Under these conditions neither flotation nor gravity separation can be used to separate dolomite from magnesite. Microscopic investigation revealed that there is a difference in the magnetic properties between dolomite and magnesite which can be separated using a magnetic separation technique. In this case, most of the magnesite which associated with magnetite and hematite minerals will be separated as a strongly magnetic fraction. On the other hand, dolomite stained with goethite and lepidocrocite will be separated as a weakly magnetic fraction. Besides, using such technique, magnesite will be cleaned from the non-magnetic minerals such as quartz and serpentine. However, the aim of this work was to reduce the dolomite content (represented by CaO) to a minimum value and prepare a magnesite product suitable for basic refractory using magnetic separation technique.

Dry magnetic separation of the carbonate sample

Magnetic separation is a direct physical process based on the difference in magnetic susceptibility for minerals under investigation. Magnetic susceptibility (ξ) is expressed as:

$$\xi = \rho \chi \tag{1}$$

where χ is the specific magnetic susceptibility and ρ is the material density. The relevant susceptibilities are as follows:

– strongly magnetic $\xi > 10^{-5}$ m^3/kg
– feebly magnetic $\xi = 10^{-6}$ to 0.5×10^{-7} m^3/kg
– non-magnetic $\xi < 10^{-8}$ m^3/kg.

Table 2 presents the magnetic susceptibility for different minerals found in the studied sample (Schubert, 1978). It is seen that these minerals are amenable to be separated using magnetic separation process. The “Carpco” induced roll magnetic separator with variable speed controller from 0.0 to 100 rpm was used in this study. The generated centrifugal force, with the free fall of the feed, creates favourable conditions for separation using that machine.

Table 2. Magnetic susceptibility for different minerals (Schubert, 1978)

Mineral	Chemical formula	Magnetic susceptibility, $\cdot 10^{-9}$ m^3/kg
Magnetite	Fe_3O_4	0.2 to $18\cdot10^6$
Hematite	Fe_2O_3	500-3800
Goethite	FeO(OH)	250-300
Dolomite	$CaMg(CO_3)$	15
Magnesite	$MgCO_3$	–6.4 to +45
Talc	$Mg_3Si_4O_{10}(OH)_2$	–
Serpentine	$Mg_3Si_2O_5 (OH)_4$	60-1200
Quartz	SiO_2	–5.7

Effect of magnetic field strength

The effective capture of fine particles, using dry high intensity magnetic separation, depends mainly on the magnetic attractive force radially inwards as well as the other competing forces including centrifugal radially outwards and gravitational forces downwards. The magnetic attracting forces acting on a particle are the product of the particle magnetization and the magnetic field gradient (Cohen, 1973; Arvidson, 1995).

The effect of magnetic field strength on the magnesite-dolomite separation was studied at a constant drum speed, 40 rpm (Fig. 2 and Table 3). It is seen that there is no significant change in CaO until the field intensity of 1.0 Ampere, after which there is a gradual increase in the CaO content in the magnetic fraction (magnesite concentrate). This is due to mechanical entrapment and non-selective magnetic capture of the entrained non-magnetic particles in the clusters of the magnetic particles. However, using magnetic field strength of one Ampere a magnesite concentrate assaying 2.43% CaO with an operational recovery 38.44% was obtained from a feed assaying 5.73% CaO. On the other hand, the wt% of the non-magnetic fraction, mainly dolomite, was decreased with increasing the magnetic field strength. However, it can be seen that the optimum conditions for magnesite-dolomite separation could be achieved at a magnetic field of 1.0 Ampere.

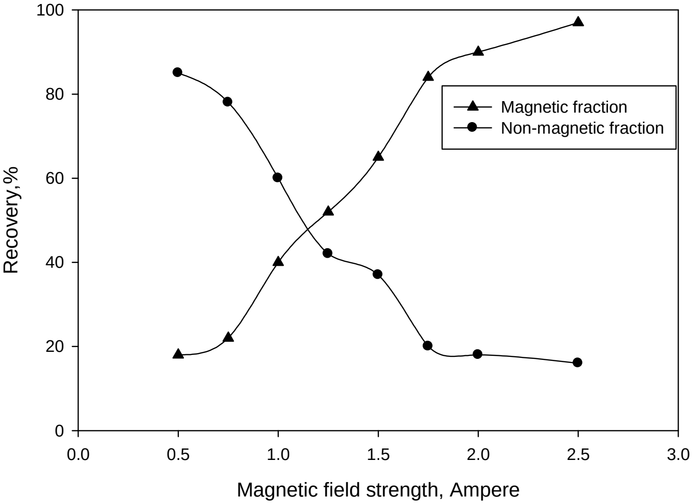


Fig. 2. Effect of magnetic field strength on magnesite-dolomite separation

Table 3. Effect of magnetic field strength on CaO content in magnetic and non-magnetic fractions

Magnetic field strength, Ampere	CaO, %	
	Magnetic	Non-magnetic
0.5	2.21	6.35
0.75	2.33	6.69
1.00	2.43	7.79
1.25	3.38	8.66
1.5	4.56	7.63
1.75	5.46	6.75
2.00	5.43	7.93
2.5	5.59	5.79

Effect of drum speed

The rotation speed of the drum represents the most critical parameter affecting the separation process, since it determines the centrifugal force which affects both the grade and the recovery. The centrifugal force can affect the following:

– retention time in the magnetic zone

– separation of the non-magnetic particles with high specific gravity

– detachment of very fine gangue particles adhering to the drum and to the coarse magnetic grains by residual humidity and electrostatic force.

Thus, in this case, a precise and effective adjustment between centrifugal and magnetic forces is unequivocal for reaching the equilibrium. Figure 3 and Table 4 present the effect of changing the drum speed on the dolomite-magnesite separation at a constant magnetic field (1.0 Ampere). It is seen that there is a pronounced decrease in the calcium oxide content of the magnetic fraction up to a roll speed of 60 rpm. By increasing the drum speed over this value the CaO content becomes almost constant. The lowering of calcium oxide content in the magnetic fraction with increasing the drum speed was due to the separation of the locked particles with the non-magnetic product.

Table 4. Effect of drum speed on CaO content in magnetic and non-magnetic fractions

Drum speed, rpm	CaO, %	
	Magnetic	Non-magnetic
20	3.81	8.49
40	2.43	7.79
60	1.83	7.23
80	1.82	6.59
100	1.58	6.38

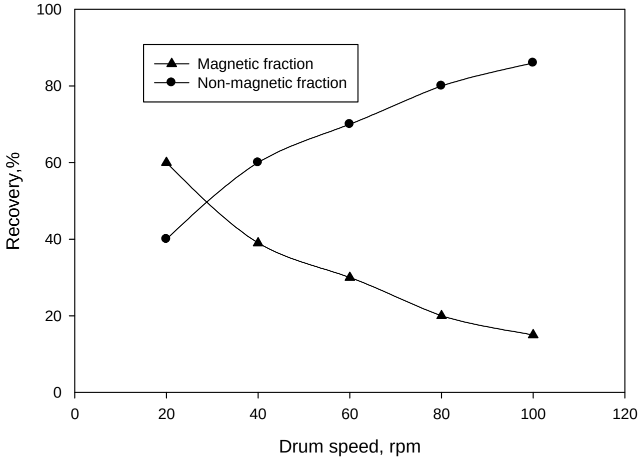


Fig. 3. Effect of drum speed on magnesite-dolomite separation

Under these conditions (60 rpm and 1 Ampere) a magnetic fraction assaying 1.83% CaO with 27.72% recovery was obtained. On the other hand, the recovery and CaO content of the non-magnetic fraction were increased with increasing the drum speed.

Cleaning of the rougher concentrate and evaluation of the separated products

An improvement in the grade of the magnetic concentrate occurs by mechanical cleaning of the rougher magnetic concentrate at 1.0 Ampere and 60 rpm. The decrease in CaO % of the cleaned concentrate, assaying 0.89% CaO, is achieved on the expense of recovery which is only 18.3 %. Two scavenging steps for the non-magnetic fractions were conducted at higher magnetic field strength of 1.25 and 2 Ampere and at 60 rpm drum speed. This step produces a middling product rich in magnesite-dolomite assaying 10.95% CaO with 44.63% recovery. However, blending of the magnetic fraction, obtained from the scavenging step, to the cleaned magnetic concentrate is recommended to achieve a reasonable concentration ratio. This produces a final magnesite concentrate assaying 1.12% CaO with 46.02% recovery (Table 5). The concentrate, with low CaO content and CaO/SiO_2 molar ratio =1.62, is suitable for making basic refractory (Girgis and Gad, 1970; Othman and Khalil, 2005). On the other hand, the middling fraction, called magnesite-dolomite product, can be used for making low-loss forsterite dielectrics. Figure 4 shows different operations used for beneficiation of the carbonate ore.

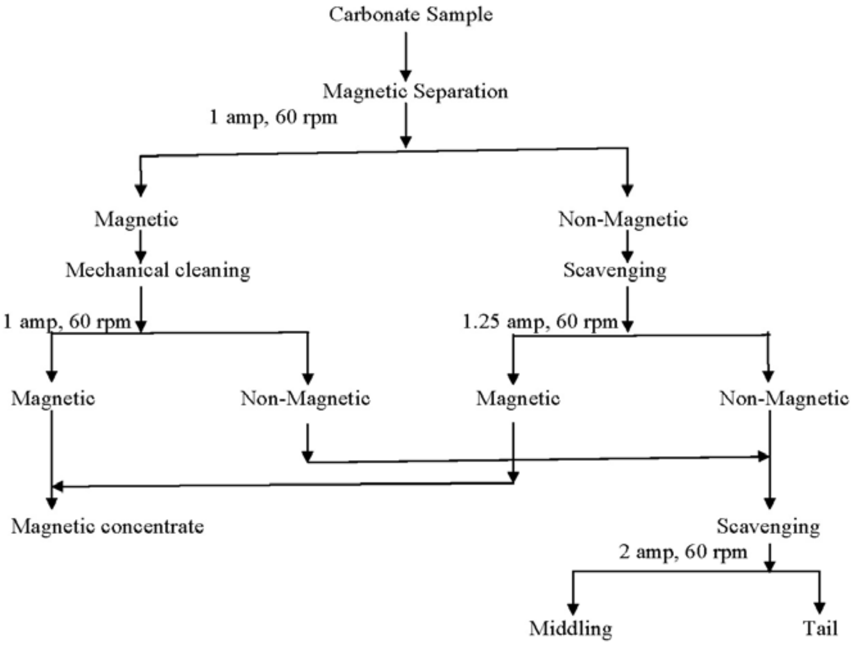


Fig. 4. Suggested flowsheet for the beneficiation of carbonate ore

Table 5. Mineral and chemical composition of the magnetic separation products

Product	Wt%	Mineral composition, %					Chemical composition, %					
		Talc	Magnesite	Dolomite	Serpentine	Quartz	SiO_2	MgO	CaO	Fe_2O_3	L.O.I.	Total
Concentrate	46.02	0.00	96.49	3.36	0.12	0.00	0.69	46.72	1.12	7.80	43.65	99.98
Middling	44.63	0.27	65.93	32.65	0.65	0.50	4.24	33.45	10.95	7.30	43.258	99.19
Tail	9.35	14.68	48.22	5.62	6.59	25.18	52.28	12.26	4.86	5.70	27.93	99.88
Feed	100	2.84	73.58	17.19	1.56	4.89	11.86	34.26	5.86	7.18	40.48	99.51

L.O.I. = Loss on Ignition

Conclusions

Microscopic analysis of the magnesite-dolomite ore sample indicates that dolomite is stained with goethite (weakly magnetic mineral), while magnesite is stained with hematite and magnetite (strongly magnetic minerals). It is suggested that iron in the ferrous state is produced upon the breakdown of ferromagnesium silicates. The released iron is oxidized when exposed on the surface to form the red coloration of the "redbeds". This iron is reduced by the ground acidic water and precipitates as goethite on dolomite surface. Iron is transported in a reduced state until it precipitates as hematite on magnesite surface when in contact with the oxidized ground water at high pH.

The magnetic technique was selected for magnesite-dolomite separation. The controlling parameters such as magnetic field strength and drum speed were changed in such a manner that the recovery-grade relationship satisfies the objectives of application. Under optimum conditions (1.0 Ampere and 60 rpm) a magnesite concentrate, assaying 1.83% CaO with 27.72% recovery, was obtained. Mechanical cleaning of the rougher magnetic concentrate produced a cleaned concentrate assaying 0.89% CaO with a recovery of 16.26 %. A scavenging step for the non-magnetic fraction was conducted. This step produced a middling product rich in magnesite-dolomite assaying 10.95% CaO with 45.78% recovery. Blending of the magnetic fraction, obtained from the scavenging step, to the cleaned magnetic concentrate is recommended to achieve a reasonable concentration ratio. This produces a final magnesite concentrate assaying 1.12% CaO with 46.02% recovery. The concentrate, with low CaO content and CaO/SiO_2 molar ratio=1.62, is suitable for making basic refractories. On the other hand, the middling fraction called magnesite-dolomite product can be used for making low-loss forsterite dielectrics.

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