

INVESTIGATION OF SOLID-SOLID INTERACTIONS BETWEEN PURE AND Li₂O-DOPED MAGNESIUM AND FERRIC OXIDES

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Abstract

The results obtained showed that the addition of small amounts of LiNO₃ to the reacting mixed solids, consisting of equimolar proportion of Fe₂O₃ and basic MgCO₃ much enhanced the thermal decomposition of magnesium carbonate. The addition of 12 mol% LiNO₃ (6 mol% Li₂O) decreased the decomposition temperature of MgCO₃ from 525.5 to 362°C. MgO underwent solid–solid interaction with Fe₂O₃ at temperatures starting from 800°C yielding MgFe₂O₄. The amount of ferrite produced increased by increasing the precalcination temperature of the mixed solids. However, the completion of this reaction required prolonged heating at elevated temperature above 1100°C. Doping with Li₂O much enhanced the solid–solid interaction between the mixed oxides leading to the formation of MgFe₂O₄ phase at temperatures starting from 700°C. The addition of 6 mol% Li₂O to the mixed solids followed by precalcination at 1050°C for 4 h resulted in complete conversion of the reacting oxides into magnesium ferrite. The heat treatment of pure and doped solids at 900–1050°C effected the disappearance of most of IR transmission bands of the free oxides with subsequent appearance of new bands characteristic for MgFe₂O₄ structure. The promotion effect of Li₂O towards the ferrite formation was attributed to an effective increase in the mobility of the various reacting cations. The activation energy of formation (ΔE) of magnesium ferrite was determined for pure and variously doped solids and the values obtained were 203, 126, 95 and 61 kJ mol⁻¹ for pure mixed solids and those treated with 1.5, 3.0 and 6.0 mol% Li₂O, respectively.

Keywords: Fe₂O₃, Li₂O-doping, MgFe₂O₄, MgO, solid–solid interactions

Introduction

Ferrites, which are usually prepared by solid-state reactions [1–17], are important materials that can be used as catalysts and in microwave devices [18–23]. Transition metal ferrites, having a cubic structure have remarkable magnetic and semiconducting properties [6, 21, 22]. Magnesium, cobalt, nickel, copper, zinc and manganese ferrites were normally employed as active catalysts in a wide variety of catalytic reac-

tions [23–30]. These reactions include oxidation, oxydehydrogenation, decomposition of alcohols and peroxides and decarboxylation of some organic acids [27–30].

Solid–solid interactions between ferric oxide and transition metal oxides or carbonates to produce the corresponding ferrites are much influenced by the prehistory of parent solids, their particle size, their ratio and also by addition of small amounts of certain foreign oxides [1–12]. In zinc ferrite formation [1–4], the reaction of ferric oxide is sharply decreased if the temperature of its preparation exceeds 675°C because of sintering. The addition of small amounts of Li₂O or Al₂O₃ enhanced solid-solid interactions between Fe₂O₃ and NiO, Co₃O₄ and ZnO to yield the corresponding ferrites [8–10]. The mechanism of ferrite formation was the object of several investigations [1–12]. The solid-solid interactions between Fe₂O₃ and transition metal oxides were reported to be the diffusion of Fe₂O₃ and metal oxide through the initially formed ferrite layer acting as an energy barrier thus hindering their further diffusion. So, the completion of these solid-state reactions requires prolonged heating at relatively elevated temperatures [8–12]. However, this energy barrier could be overcome by doping the reacting mixed solids with certain foreign oxide [8–10]. It has been reported that Li₂O doping (5 mol%) of Fe₂O₃/NiO system effected a decrease in the activation energy of formation (ΔE) of NiFe₂O₄ from 117 to 75 kJ mol⁻¹, Li₂O-treatment (3 mol%) of Fe₂O₃/Co₃O₄ led to a decrease in ΔE value of CoFe₂O₄ from 57 to 29 kJ mol⁻¹ [8, 9, 11]. Similarly, Al₂O₃-doping (5 mol%) of Fe₂O₃/NiO decreased ΔE of NiFe₂O₄ from 117 to 82 kJ mol⁻¹ [9] and doping of Fe₂O₃/ZnO with 6 mol% Al₂O₃ [12] effected a decrease in the ΔE of ZnFe₂O₄ formation from 73 to 57 kJ mol⁻¹.

The present work reports the results of a study on the effect of addition of small amounts of Li₂O on magnesium ferrite formation, at different temperatures. The techniques employed were DTA and XRD.

Experimental

Materials

Equimolar proportions of finely powdered α -Fe₂O₃ and basic magnesium carbonate solids (–150 mesh, <106 μ m) were well mixed to ensure their homogeneity. The obtained sample was heated in air at temperatures between 700 and 1050°C for 4 h. Four doped samples were obtained by adding to a known mass of mixed solids the calculated amounts of lithium nitrate dissolved in the minimum amount of distilled water, dried at 100°C, then calcined in air at 700–1050°C. The concentrations of lithium expressed as mol% Li₂O were 0.75, 1.5, 3 and 6. The chemicals employed in the present work were of analytical grade supplied by Fluka Company.

Techniques

DTA curves of pure and doped uncalcined mixed solid samples were determined using a Perkin Elmer, seven series thermal analysis system. The rate of heating was kept

at 10°C min⁻¹ and the mass of solid specimen was 40 mg. The measurements were carried out in a current nitrogen at a rate of 50 cm³ min⁻¹.

An infrared transmission spectra of various solids precalcined at different temperatures were determined using Perkin Elmer spectrophotometer (type 1430). The IR spectra were determined from 4000 to 300 cm⁻¹ but the portions between 2000 and 400 cm⁻¹ were considered in this investigation. 2 mg of each solid sample were mixed with 200 mg of vacuum-dried IR-grade KBr. The mixture was dispersed by grinding for 3 min in a vibratory ball mill and placed in a steel die 13 mm in diameter and subjected to a pressure of 12 tons. The sample disks were placed in the holder of a double-grating IR spectrometer.

An X-ray investigation of pure and variously doped-mixed solids, preheated in air at 700, 800, 900, 950, 1000, 1050°C, was conducted using a Philips diffractometer (type PW 1390). The patterns were run with iron-filtered cobalt radiation ($\lambda=1.7889 \text{ \AA}$) at 30 kV and 10 mA with a scanning speed of 2° in 2 θ per min.

Results and discussion

Thermal behavior of pure and doped mixed solids

TG and DTG investigation of the basic magnesium carbonate showed that its molecular formula was MgCO₃·Mg(OH)₂·2.5H₂O. Figure 1 depicts the DTA curves of pure

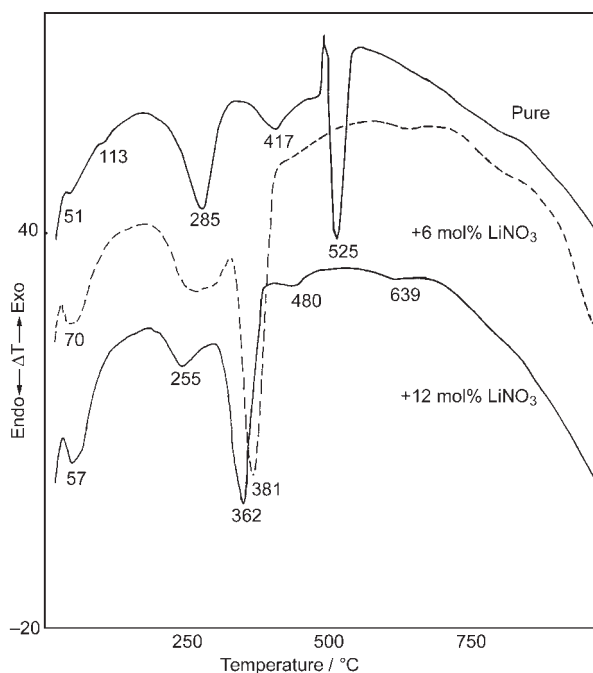


Fig. 1 DTA curves of pure and doped uncalcined mixed solids

and LiNO₃-doped uncalcined mixed solids (equimolar proportion of Fe₂O₃ and basic magnesium carbonate). The DTA curve of pure mixed solids consists of three endothermic peaks, the first and last one are sharp and strong and their maxima located at 285.4, 417.8 and 525.5°C. The first peak corresponds to dehydroxylation of basic magnesium carbonate yielding MgO and MgCO₃. The second and third peaks are indicative for the thermal decomposition of magnesium carbonate into magnesium oxide. The DTA curve of pure mixed solids did not include any thermal peak in the temperature range 600–1000°C. However, a possible solid-solid interaction might take place between the MgO produced and the ferric oxide by heating at temperatures ranged between 600 and 1000°C with a very small rate that could not be easily detected by the employed DTA technique. The DTA curves of the two doped mixed solid samples consist of five endothermic peaks, the last two peaks are weak and broad. The maxima of these peaks were found at 57, 255–278, 362–380, 480 and 639°C. The first three peaks correspond to the thermal decomposition of basic magnesium carbonate into MgO. The comparison of DTA curves of pure and doped mixed solids revealed that lithium doping much enhanced the thermal decomposition of basic magnesium carbonate into magnesium oxide. The endothermic peak relative to thermal decomposition of magnesium carbonate was shifted from 525.5 to 382 and 362°C for the 6 and 12 mol% LiNO₃-treated mixed solids (3 and 6 mol% Li₂O), respectively. These results which agree with those of mass loss measurements previously given in present work showed that lithium nitrate enhanced the thermal decomposition of basic magnesium carbonate to an extent proportional to its amount added (in the range 0.75–6 mol% Li₂O). The endothermic peak at 480°C found in the DTA curve of the 6 mol% lithium nitrate-doped mixed solids sample might correspond to thermal decomposition of lithium nitrate yielding Li₂O [5].

The last endothermic peak in the DTA curves of doped mixed solids found at 639°C might characterize a solid–solid interaction between MgO and Fe₂O₃ that producing magnesium ferrite phase. The identification of this phase could be achieved by XRD analysis of the calcination products of pure and variously doped mixed solids.

IR spectrophotometric investigation of various solids

The IR transmission spectra were measured for ferric oxide, magnesium oxide precalcined at 700°C and pure and variously doped mixed solids preheated at 900 and 1050°C. It is observed from Fig. 2 that the spectrum of ferric oxide consisted of very strong bands at 453, 534 and 1050 cm⁻¹ besides sharp and relatively weak bands at 363 and 775 cm⁻¹ while very weak and sharp band at 394 cm⁻¹ was only detected in the spectrum of MgO precalcined at 700°C. It can also be seen from Fig. 2 that the strong band at 1053 cm⁻¹ found in the spectrum of ferric oxide disappeared in the spectra of pure and doped mixed solids precalcined at 900°C with subsequent appearance of two bands at 900 and 1000 cm⁻¹. The intensity of the newly bands appeared at 900 and 1000 cm⁻¹ (Fig. 2) increased by increasing the amount of Li₂O added to the mixed solids precalcined at 900°C. The spectra of pure and variously doped solids precalcined at 1000°C, not given, are similar to those observed for different solids precalcined at 900°C. It can be observed

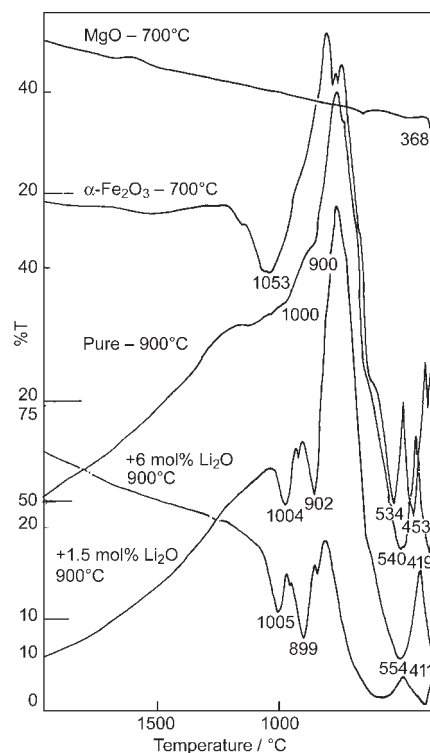


Fig. 2 IR-transmission bands of $\text{MgO} - 700^\circ\text{C}$, $\text{Fe}_2\text{O}_3 - 700^\circ\text{C}$ and pure doped mixed solids precalcined at 900°C

from Fig. 3 that the spectra of pure and doped mixed solids consisted of four strong and sharp bands at $353\text{--}422$, $540\text{--}567$, 900 and 1000 cm^{-1} and the intensity of these bands increased by increasing the amount of dopant added. These bands might characterize structures different from those of individual ferric and magnesium oxides. These results clearly indicate that the heat treatment of pure and Li_2O -doped MgO and Fe_2O_3 at temperatures in the range of $900\text{--}1050^\circ\text{C}$ resulted in the disappearance of most of free oxides with subsequent appearance of magnesium oxide–ferric oxide compound. Furthermore, the addition of small amounts of Li_2O ($0.75\text{--}6\text{ mol}\%$) to the mixed solids enhanced the formation of magnesium–iron compound to an extent proportional to its amount added. X-ray investigation of pure and variously doped mixed solids precalcined at $700\text{--}1050^\circ\text{C}$ achieved the identification or characterization of newly formed compound.

X-ray investigation of pure and doped solids precalcined at $700\text{--}1050^\circ\text{C}$

The X-ray diffractograms were determined for pure and doped ferric oxide and magnesium carbonate mixtures precalcined at 700 , 800 , 900 , 950 , 1000 and 1050°C . The diffractograms of Fe_2O_3 and magnesium carbonate mixture preheated at 700°C (not given) correspond to very well crystallized $\alpha\text{-Fe}_2\text{O}_3$ and MgO phases. The diffracto-

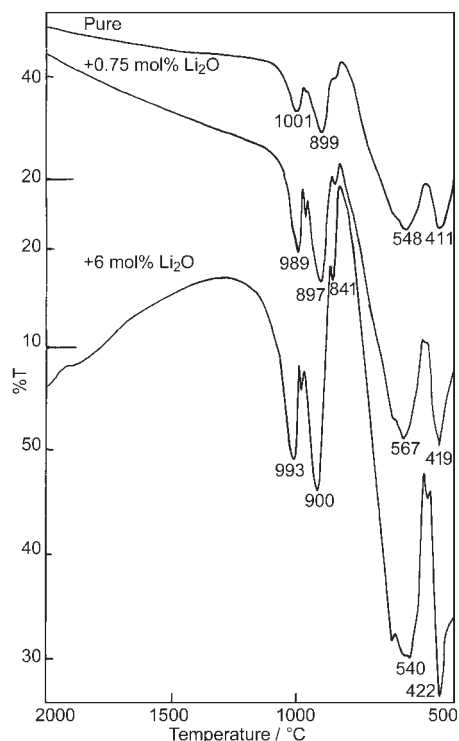


Fig. 3 IR-transmission bands of pure and doped mixed solids precalcined at 1050°C

grams of pure and variously doped mixed solids precalcined at 700°C (not given) consisted of all the diffraction lines of well crystallized α -Fe₂O₃ phase and some lines of MgO and γ -Fe₂O₃ phases.

These results might indicate the absence of any appreciable solid–solid interaction between pure Fe₂O₃ and MgO when precalcined at 700°C. However, the addition of increasing amounts of Li₂O followed by precalcination at 700°C resulted in a progressive decrease in the intensity of the diffraction lines of unreacted α -Fe₂O₃. In fact, the peak height of the line at 2.69 Å (100% of α -Fe₂O₃ phase) decreased from 101 to 63 mm upon the addition of 6 mol% Li₂O (Table 1). Furthermore, the ratio between the relative intensity of the diffraction lines at 2.51 and 2.69 Å [26] increased from 55% to 73% due to the addition of the least amount of Li₂O (0.75 mol%). The diffraction line at 2.51 Å is common for α -Fe₂O₃ (50%) and MgFe₂O₄ (100%) and that at 2.69 Å corresponds to α -Fe₂O₃ (100%). These findings might suggest that Li₂O-treatment of MgO and Fe₂O₃ followed by precalcination at 700°C resulted in the formation of a small amount of the MgFe₂O₄ phase.

Figures 4 and 5 depict the diffractograms of pure and variously doped mixed solids precalcined at 800 and 1000°C for 4 h. It is seen from Fig. 4 that the diffracto-

grams of pure mixed solids sample and those treated with 0.75 mol% Li₂O followed by precalcination at 800°C consisted of α -Fe₂O₃, γ -Fe₂O₃ and MgO phase, similar to all investigated mixed solids precalcined at 700°C. On the other hand, a new diffraction line at 2.96 Å appeared in the patterns of the other doped (1.5–6% Li₂O) mixed solids preheated at 800°C. This line at 2.96 Å characterizes MgFe₂O₄ (40%) [31]. The area of the diffraction peak at 'd' spacing of 2.96 Å increased by increasing the amount of Li₂O added (Fig. 4).

Table 1 The effects of precalcination temperature and doping on the height of some diffraction lines at 'd' spacing of 2.69 Å (100% α -Fe₂O₃), 2.51 Å (100% MgFe₂O₄ and 50% α -Fe₂O₃)

Solids	Precalcination temperature/°C	Peak height		Ratio between b/a
		2.69 Å(a)	2.51 Å(b)	
Pure MgO+Fe ₂ O ₃	700	101	56	0.55
+0.75 mol% Li ₂ O		82	60	0.73
+1.5 mol% Li ₂ O		72	53	0.73
+3 mol% Li ₂ O		72	53	0.73
+6 mol% Li ₂ O		63	46	0.73
Pure MgO+Fe ₂ O ₃	800	84	63	0.75
+0.75 mol% Li ₂ O		77	60	0.78
+1.5 mol% Li ₂ O		68	58	0.86
+3 mol% Li ₂ O		68	62	0.91
+6 mol% Li ₂ O		60	68	1.13
Pure MgO+Fe ₂ O ₃	900	84	70	0.83
+0.75 mol% Li ₂ O		75	78	1.04
+1.5 mol% Li ₂ O		52	68	1.31
+3 mol% Li ₂ O		50	90	1.80
+6 mol% Li ₂ O		38	110	2.90
Pure MgO+Fe ₂ O ₃	950	100	85	0.85
+0.75 mol% Li ₂ O		78	123	1.58
+1.5 mol% Li ₂ O		65	96	1.48
+3 mol% Li ₂ O		60	120	2.00
+6 mol% Li ₂ O		28	101	3.62
Pure MgO+Fe ₂ O ₃	1000	55	100	1.82
+0.75 mol% Li ₂ O		37	130	3.51
+1.5 mol% Li ₂ O		32	128	4.00
+3 mol% Li ₂ O		24	139	5.80
+6 mol% Li ₂ O		5	158	31.6
Pure MgO+Fe ₂ O ₃	1050	75	117	1.56
+0.75 mol% Li ₂ O		32	164	5.12
+1.5 mol% Li ₂ O		39	179	4.60
+3 mol% Li ₂ O		20	145	7.25
+6 mol% Li ₂ O		0	157	∞

The role of precalcination temperature and treatment with small amounts of Li₂O in the solid–solid interaction between Fe₂O₃ and MgO producing magnesium

ferrite is better investigated by measuring the height of certain diffraction lines characteristic for α -Fe₂O₃ and relative to one of the common lines of both MgFe₂O₄ and α -Fe₂O₃ phases. This was done and the results obtained are given in Table 1. Inspec-

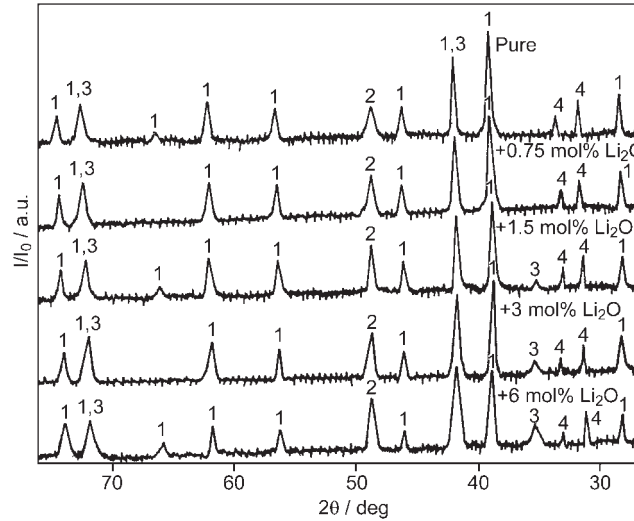


Fig. 4 XRD diffractograms of pure and variously doped mixed solids precalcined at 800°C, lines 1, 2, 3 and 4 refer to α -Fe₂O₃, MgO, MgFe₂O₄ and γ -Fe₂O₃, respectively

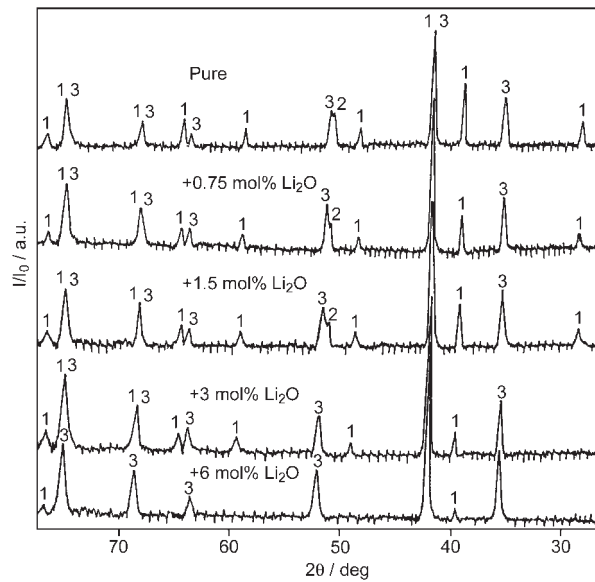
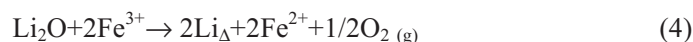


Fig. 5 XRD diffractograms of pure and variously doped mixed solids precalcined at 1000°C, lines 1, 2, 3 and 4 refer to α -Fe₂O₃, MgO, MgFe₂O₄ and γ -Fe₂O₃, respectively

tion of this table revealed that: (i) The ratio (R) between the peak height of the lines at 'd' spacing of 2.51 and 2.69 Å for pure mixed oxides precalcined at 700°C is 0.55 which is close to that of pure α -Fe₂O₃ (0.50). This indicates the absence of MgFe₂O₄ phase. (ii) The addition of small amounts of Li₂O followed by precalcination at 700°C led to a measurable increase in the value of R with subsequent decrease in peak height of line at 2.69 Å relative to the unreacted α -Fe₂O₃ phase. This finding suggests the enhancement of MgFe₂O₄ formation due to Li₂O treatment at 700°C. (iii) The increase in the temperature of heat treatment of various solids investigated in the range of 700–1050°C resulted in progressive increase in the value of R indicating a progressive increase in the extent of produced MgFe₂O₄ phase. (iv) The increase in the amount of Li₂O added to mixed solids precalcined at various temperatures between 800 and 1050°C brought about a progressive increase in the value of R with subsequent progressive decrease in the height of the line at 'd' spacing of 2.69 Å. (v) The addition of 6 mol% Li₂O to mixed solids precalcined at 1050°C for 4 h resulted in the complete disappearance of all diffraction lines of unreacted α -Fe₂O₃ phase and its complete conversion into MgFe₂O₄ phase.

The promotion effects of Li₂O towards the formation of Ni, Co, Zn and copper ferrites have been reported [8–12]. The treatment NiO/Fe₂O₃, Co₃O₄/Fe₂O₃ and ZnO/Fe₂O₃ solids with small amounts of Li₂O enhanced the formation of nickel, cobalt, and zinc ferrites and led, also, to the formation of β -lithium ferrite β -LiFeO₂ [5, 9]. It has been reported that Na₂O-doping enhanced the solid-solid interactions in V₂O₅/Al₂O₃ system [32].

Fe₂O₃ and MgO undergo a solid–solid interaction to produce MgFe₂O₄ that covers the grains of each reacting oxide [8–10]. The propagation of this reaction is controlled by the thermal diffusion of magnesium and iron cations through the ferrite film, which acts as an energy barrier. The fact that free Fe₂O₃ and MgO phase were detected in pure mixed solids precalcined at 1050°C for 4 and 24 h, gives an indication of the height of the energy barrier which has to be overcome. Similar results have been reported in the case of NiO/Fe₂O₃ system doped with Li₂O [8, 9]. Although, lithia stimulated NiFe₂O₄ formation was incapable of effecting a complete conversion of the reacting oxides into nickel ferrite even by precalcination at 1100°C [5, 8–10], this is considered as a special case for Li₂O dopant because of the big solubility of lithia in NiO lattice, which dissolves more than 16 mol% Li₂O. This process increased much the mobility of nickel cations, facilitating thus the NiFe₂O₄ formation, but effected the conversion of some of Ni²⁺ into Ni³⁺ ions which did not contribute to the ferrite formation. The observed enhancement of MgFe₂O₄ formation due to doping with lithium oxide may be a consequence of an effective increase in the mobility of Mg²⁺ and Fe³⁺ cations. In contrast with the case of NiO/Fe₂O₃, Co₃O₄/Fe₂O₃, ZnO/Fe₂O₃ systems [5, 8–10], Li₂O-doping of MgO/Fe₂O₃ solids did not result in the formation of lithium ferrite. In other words, all the lithia added dissolved completely in the lattices of MgO and Fe₂O₃, solids forming solid solutions. The dissolution process can be simplified by the use of Kroger's mechanism [33] in the following manner:



Li (Mg²⁺), Li (Fe³⁺) are monovalent lithium ions located in the positions of host cations Mg²⁺ and Fe³⁺ of MgO and Fe₂O₃ lattices, A. V. and C. V. are created anionic and cationic vacancies, Li_Δ is monovalent lithium ion retained in interstitial positions in MgO and Fe₂O₃ lattices. Reactions 1 and 3 indicate that the dissolution of 2Li⁺ ions in the lattice of MgO and Li⁺ ion in the lattice of Fe₂O₃ is followed by creation of one anionic vacancy in each doped solid.

Table 2 The effects of Li₂O-doping and precalcination temperature on the height of selected diffraction line at 'd' spacing of 2.96 Å

Solids	Precalcination temperature/°C	Peak height/mm 2.96 Å (40% MgFe ₂ O ₄)*
Pure MgO+Fe ₂ O ₃		8
+0.75 mol% Li ₂ O		16
+1.5 mol% Li ₂ O	900	24
+3 mol% Li ₂ O		28
+6 mol% Li ₂ O		38
Pure MgO+Fe ₂ O ₃		20
+0.75 mol% Li ₂ O		30
+1.5 mol% Li ₂ O	950	37
+3 mol% Li ₂ O		40
+6 mol% Li ₂ O		50
Pure MgO+Fe ₂ O ₃		44
+0.75 mol% Li ₂ O		48
+1.5 mol% Li ₂ O	1000	50
+3 mol% Li ₂ O		53
+6 mol% Li ₂ O		59
Pure MgO+Fe ₂ O ₃		40
+0.75 mol% Li ₂ O		50
+1.5 mol% Li ₂ O	1050	63
+3 mol% Li ₂ O		68
+6 mol% Li ₂ O		75

*The line of 100% MgFe₂O₄ coincides with that of 50% α-Fe₂O₃ phases

The dissolution of lithium oxide in the lattices of MgO and Fe₂O₃ according to reactions (1)–(3) is expected to be accompanied by an increase in the mobility of Mg²⁺ and Fe³⁺ cations due to creation of anionic and cationic vacancies. On the other hand, incorporation of Li₂O in the lattice of Fe₂O₃ according to reaction (4) did not favour the formation of magnesium ferrite because of transformation of some of Fe³⁺

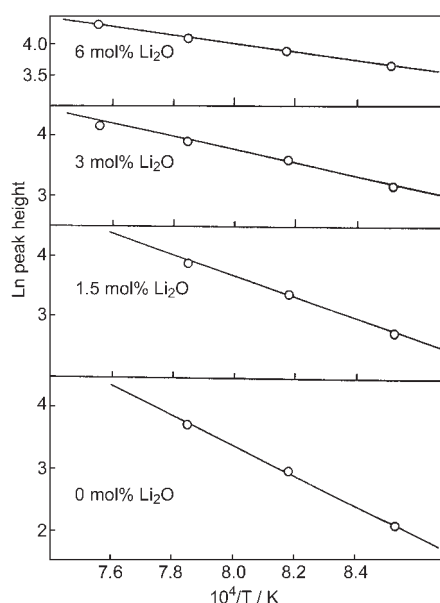


Fig. 6 Change of ln peak height of the diffraction line of MgFe₂O₄ (2.96 Å) as a function of precalcination temperature for pure and Li₂O-doped mixed solids [11, 12]

into Fe²⁺ cations, which did not contribute in MgFe₂O₄ formation. The fact that Li₂O-doping followed by precalcination at 700–1050°C enhanced the formation of magnesium ferrite formation to an extent proportional to its amount added suggested that most of the dopant added is dissolved in MgO and Fe₂O₃ according to reactions (1)–(3). The speculated induced increase in the mobility of the reacted cations due to treatment with Li₂O as a result of creation of anionic and cationic vacancies could be investigated by the determination of the activation energy of formation of MgFe₂O₄ phase (ΔE) at temperatures between 900 and 1000°C for pure and doped mixed solids. This has been tentatively achieved from the results given in Table 2, assuming that the height of the characterized diffraction line at 2.96 Å provides a measure of the amount of MgFe₂O₄ present in a given solid sample at a definite temperature (T). By plotting the peak height of this line vs. $1/T$, a straight line is obtained, the slope of which determines ΔE value by the direct application of Arrhenius equation. This test has been successfully done at 900, 950 and 1000°C and the obtained plots are given in Fig. 6 for pure and variously doped mixed solids. The computed ΔE values are 203, 126, 95 and 61 kJ mol⁻¹ for pure mixed solids sample and those doped with 1.5, 3.0 and 6 mol% Li₂O, respectively. This considerable decrease in ΔE value due to the doping process reflects clearly the role of Li₂O-treatment in increasing effectively the mobility of the reacting cations.

Conclusions

The main conclusions that may be drawn from the results obtained are the following:

- Treatment of equimolar proportion of basic magnesium carbonate and ferric oxide with small amounts of LiNO₃ in the range of 1.5–12.0 mol% (0.75–6 mol% Li₂O) enhanced much the thermal decomposition of MgCO₃ to an extent proportional to its amount added. The addition of 6 mol% lithium nitrate decreased the decomposition-temperature of MgCO₃ from 525.5 to 362°C.
- MgO interacted with Fe₂O₃ at temperatures starting from 800°C yielding MgFe₂O₄. The prolonged heating of pure mixed solids at 1050°C for 24 h effected the partial conversion of the reacting oxides into the ferrite phase.
- Li₂O-doping of MgO and Fe₂O₃ mixed solids followed by precalcination at temperatures starting from 700°C resulted in an enhanced formation of MgFe₂O₄ phase. The stimulation effect of MgFe₂O₄ formation due to treatment with small amounts of Li₂O was increased by increasing its amount added (in the range of 0.75–6 mol% Li₂O).
- The addition of a very small amount of Li₂O (0.75 mol%) followed by precalcination at 1050°C for 4 h brought about the conversion of most of reacting oxides into MgFe₂O₄ phase.
- The computed values of activation energy of formation of magnesium ferrite were 203, 126, 95 and 61 kJ mol⁻¹ for pure mixed solid samples and those doped with 0.75, 1.5 and 6 mol% Li₂O, respectively.

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