CHAPTER IV

Magnetic properties

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MAGNETIC PROPERTIES

4.1 Introduction

The magnetic materials have wide range of applications. Ferrites possess high values of magnetization because of imbalanced site magnetic moments, high values of resistivity, low dielectric loss and high Neel temperature [1]. These properties have made them versatile materials for various technological applications such as radio, television, microwave and satellite communication, bubble devices, audio, video and digital recording [2]. The ferrites such as Ni-Zn are soft ferrimagnetic materials having low magnetic coercivity, high resistivity value [3] and current loss in high frequency operation (10-500MHz) [4]. This highly magnetic nature of ferrites, also plays an important role in realizing the ME phenomenon [5]. It is well known that the properties of ferrite material depend upon their composition and microstructure [6]. Also the magnetic behaviour of ferrites depends on a number of other parameters like cation distribution, site preference energies, covalency of bonds and molecular field [7, 8].

a. Magnetic moment and magnetization

Electrons spin about an axis and by virtue of this spin and their electrostatic charge, exhibit magnetic moment. The region in which their alignment occurs are called domains and this may extend over many thousands of unit cells.

Magnetization is defined as the magnetic moment per unit volume and is therefore proportional to the density of magnetic ions and to their magnetic moments.

b. Domains and domain boundaries

The crystallite is normally divided into a number of domains of various spin orientations [9]. The ferromagnetic material is characterized by domain structure in which each domain has spontaneous magnetization. [10].

These domains are separated by walls, the Bloch walls, which consists of a certain number of atomic planes in which the orientation of the magnetic moments more or less progressively passes from that of one domain to that of the other.

In the samples with few defects, walls move nearly freely so that the macroscopic magnetization reaches the spontaneous magnetization for a very weak internal magnetic field, such material will be termed as soft ferromagnetic. If there is large number of defects, they constitute obstacles to the wall motion so that the magnetization increases more slowly as a function of the applied field. This is the case of hard ferromagnetic materials.

c. Magnetic anisotropy

The magnetization of a magnetic material may be easy or difficult which depends upon the direction. Such dependence of strength of magnetization on the direction of magnetization is known as magnetic anisotropy and the energy required to turn the magnetization from the preferred direction to the desired direction is known as anisotropy energy [11]. It is due to the magnetic interaction between the magnetic dipoles and their arrangement in lattice [12, 13].

d. Magnetostriction

When magnetic field is applied to a magnetic material, it either shrinks or expands in the direction of field. If the shrinking is in the direction of field then it is called as negative magnetostriction and if it expands it is considered positive magnetostriction. This phenomenon of change in dimensions of magnetic material during the magnetization is called magnetostriction. For good ME output, the basic requirement is that the ferrite phase should have large value of magnetostriction.

e. Magnetic hysteresis

The ferrimagnetic materials consist of magnetic domain with randomly oriented spins. On application of magnetic field, the domains tend to orient in the direction of the magnetic field and magnetization reaches a saturation value.

When the field is reversed due to the irreversible domain wall movements the magnetization lags behind the field and the open loop results. This loop is called as hysteresis loop [Fig. 4.1]. The phenomenon is known as magnetic hysteresis.

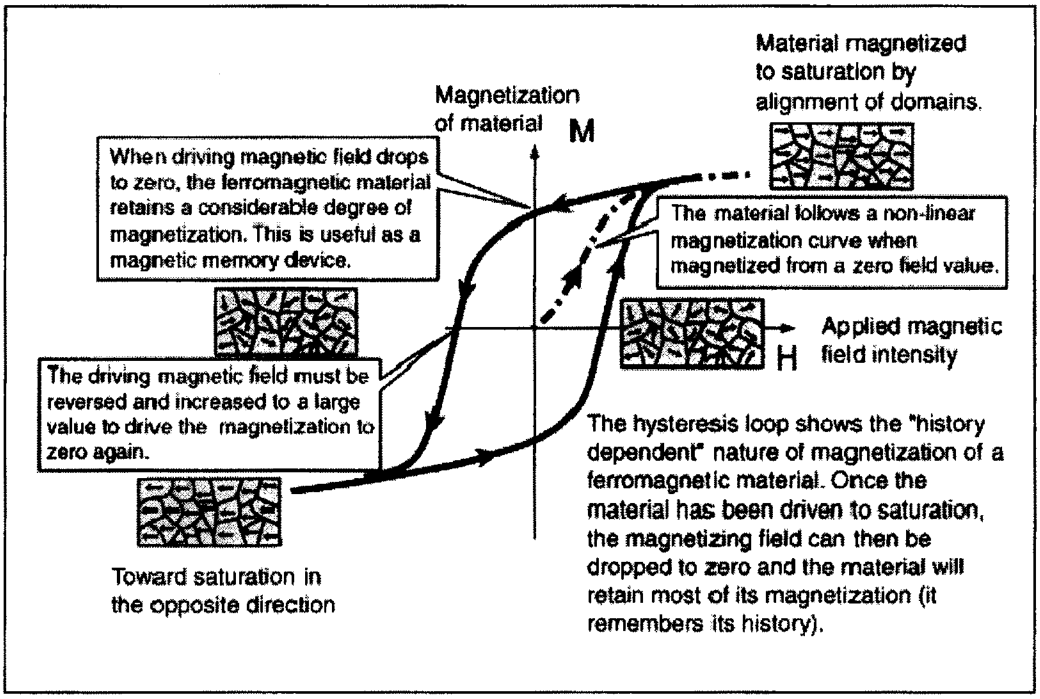

Fig. 4.1 Schematic diagram of hysteresis loop

Even after reversing the field from saturation value towards zero, some magnetization is retained. This is called as residual or remanent magnetization (Mr). When the direction of magnetic field is reversed, the remanent magnetization reduces and finally become zero at certain magnetic field called as coercive field (Hc).

4.2 Experimental techniques

The magnetization measurements of the samples was carried out by using the high field hysteresis loop tracer, designed by Tata Institute of Fundamental Research, Mumbai, connected to the computerized system.

The system was firstly calibrated with the help of standard nickel sample of known saturation magnetization (Ms = 52.83 emu/gm) and mass 0.695 gm. After calibration, replacing the nickel sample by the samples under study one by one, the magnetic measurements were carried out providing the weight of individual sample. The magnetic moment in Bohr magneton was calibrated by using the relation between σ' and μ_B as

$$\sigma = (\mu_B N_A / M) \text{ x } \eta_B \qquad \ldots (1)$$

$$= (5585 / M) \text{ x } \eta_B \qquad \ldots (2)$$

$$\eta_B = (\sigma' \text{ x } M) / 5585 \qquad \ldots (3)$$

Where,

N_A is the Avogadro's number (6.024 x 10^{23} gm / mol)

M is molecular weight of sample

μ_B is Bohr magneton (9.273 x 10^{-21} emu)

4.3 Results and Discussion

The typical magnetic hysteresis plots for the ferrites $Co_{0.9}Cd_{0.1}Fe_2O_4$ and $Co_{0.7}Cd_{0.3}Fe_2O_4$ are shown in the Fig. 4.2 and 4.3 respectively. They show the variation of saturation magnetization with Cd content. This is due to the fact that, Cd^{2+} ion is non magnetic and has tendency to occupy tetrahedral site [14]. The substitution of Co^{2+} by Cd^{2+} causes the migration of Fe^{3+} ions to octahedral sites

(B sites). The concentration of Fe^{3+} ions with higher spin magnetic moment than Co^{2+} by Cd^{2+} leads an increase in the resultant magnetization [15].

Figs. 4.4 - 4.9 show the magnetic hysteresis loops for all the composites. The values of saturation magnetization (Ms), coercivity (Hc), remanent magnetization (Mr) and magnetic moment (η_B) are listed in Table 1. The variation of Ms, Hc and η_B with mole % of ferrite is as shown in Figs. 4.10, 4.11, 4.12 respectively.

The values of saturation magnetization (Ms), coercivity (Hc), remanent magnetization (Mr) and magnetic moment (η_B) are listed in Table 1. The values of M_s and μ_B obey the rule of mixtures.

$$M_{s\,(composite)} = x\,Ms_{(Ferrite)} + (1-x)\,Ms_{(Ferroelectric)} \qquad \ldots (4)$$

where, x is the mole fraction of ferrite phase. Since

$$M_{s\,(ferroelectric)} = 0 \qquad \ldots (5)$$

$$\therefore\ M_s(composite) = x\,Ms\,(ferrite) \qquad \ldots (6)$$

It is known that larger grains tend to consist of a greater number of domain walls. The magnetization caused by domain wall movement requires less energy than that required by domain rotation. As the number of walls increases with grain size, the contribution is more. Hence samples having larger grain size are expected to have low coercivity (Hc) [16].

From the plots it is clearly seen that the saturation magnetization for the composites is less than that for ferrites. This is attributed to the presence of pores among the grains which breaks the magnetic circuits and results in reduction in magnetic properties [17]. In composites, in the presence of magnetic field the ferroelectric material acts as a pore causing a reduction in saturation magnetization. The value of the remanent magnetization for the present series suggests that most of the magnetization vectors are turned in the magnetically preferred direction making small angle with direction of applied field. This results in stress which results in increasing magnetization [18].

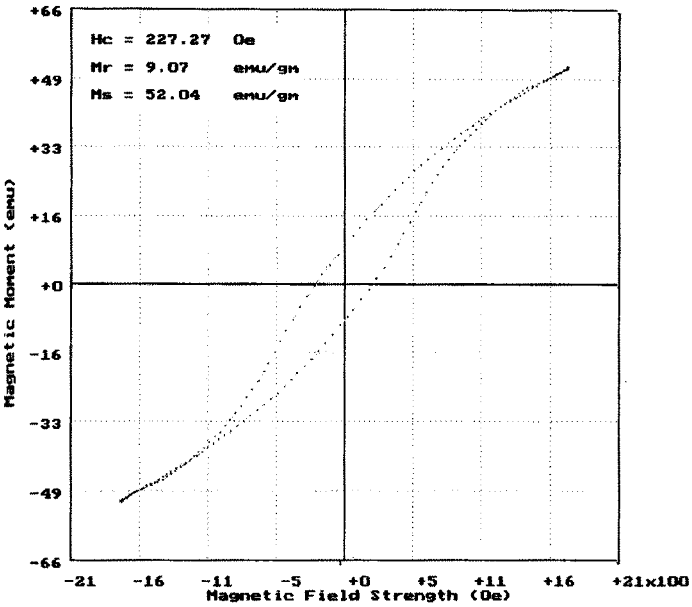

Fig.4.2 Hysteresis plot of $Co_{0.9}Cd_{0.1}Fe_2O_4$ ferrite

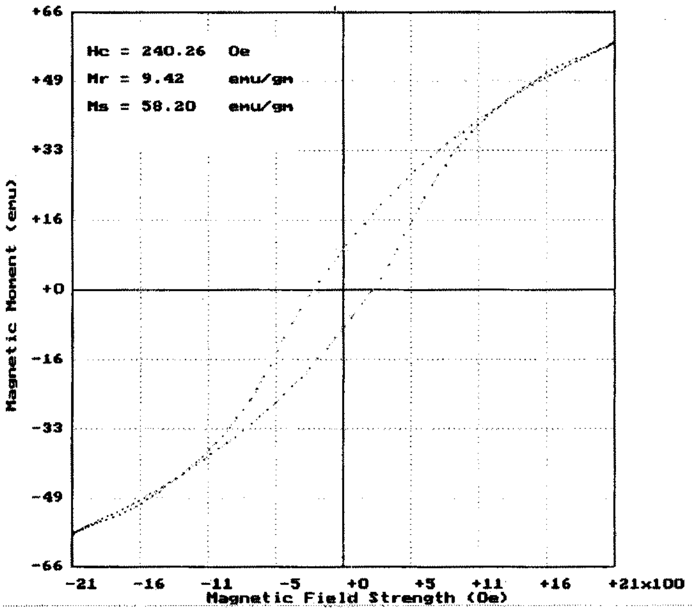

Fig.4.3 Hysteresis plot of $Co_{0.7}Cd_{0.3}Fe_2O_4$ ferrite

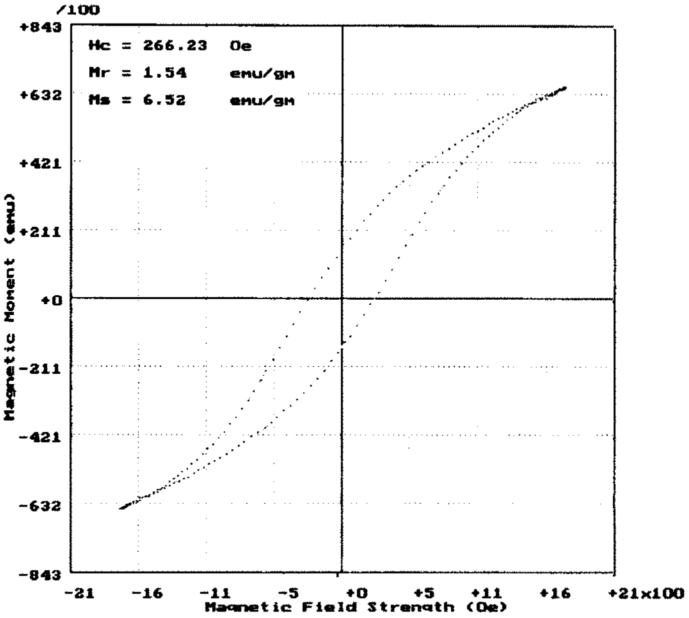

Fig.4.4 Hysteresis plot of (0.15)$Co_{0.9}Cd_{0.1}Fe_2$04 + (0.85) PZT MEcomposite

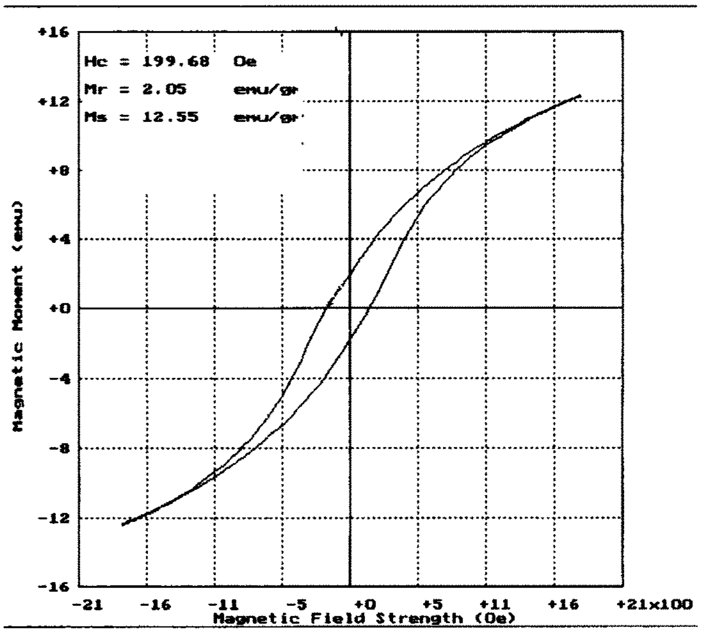

Fig.4.5 Hysteresis plot of (0.30)$Co_{0.9}Cd_{0.1}Fe_2$04 + (0.70) PZT ME composite

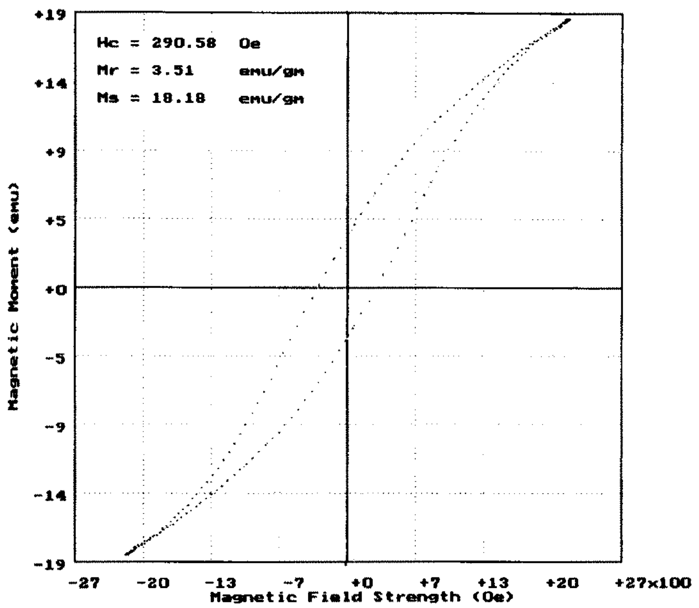

Fig.4.6 Hysteresis plot of (0.45)$Co_{0.9}Cd_{0.1}Fe_2O_4$ + (0.55) PZT ME composite

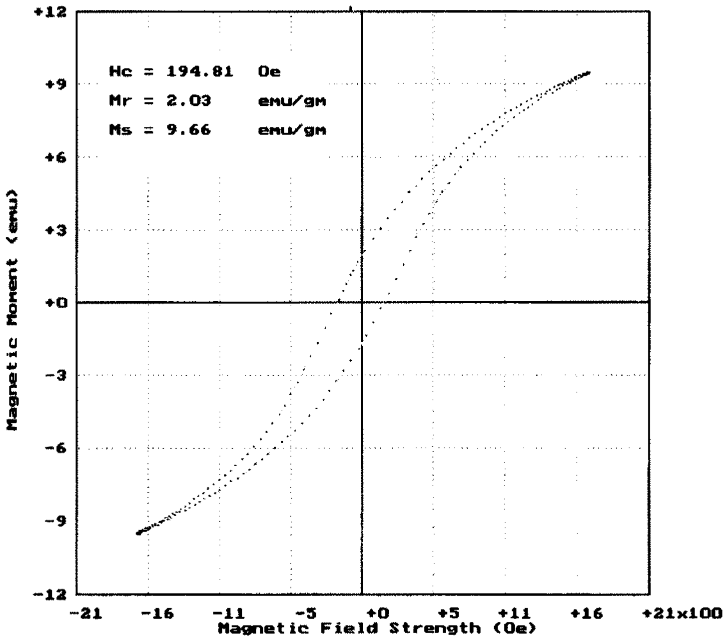

Fig.4.7 Hysteresis plot of (0.15) $Co_{0.7}Cd_{0.3}Fe_2O_4$ + (0.85) ME composite

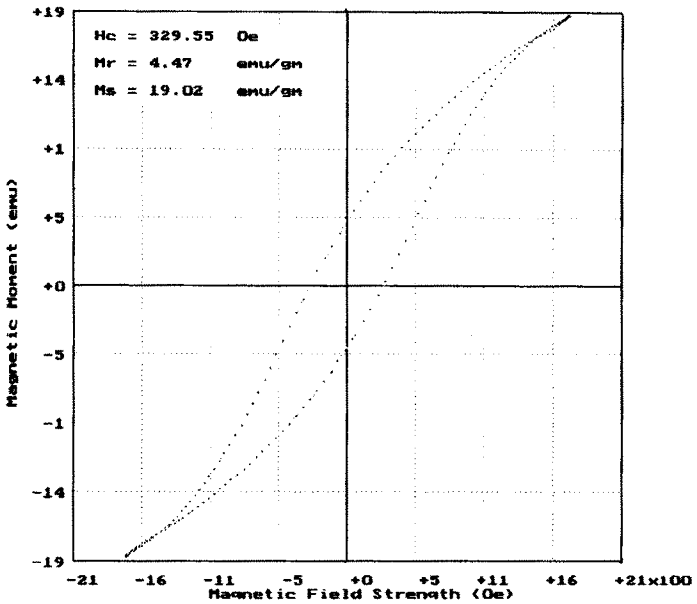

Fig.4.8 Hysteresis plot of (0.30)$Co_{0.7}Cd_{0.3}Fe_2O_4$ + (0.70) PZT ME composite

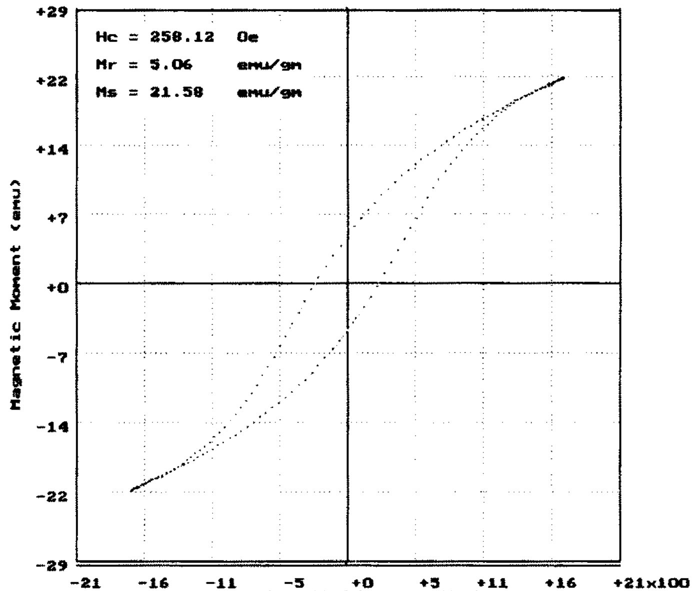

Fig.4.9 Hysteresis plot of (0.45) $Co_{0.7}Cd_{0.3}Fe_{2}O4$ + (0.55) PZT ME composite

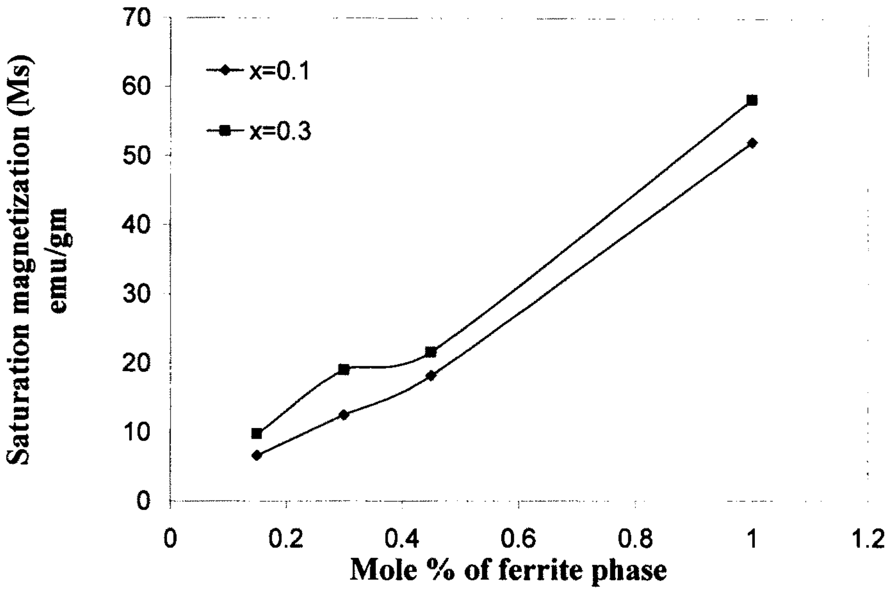

Fig.4.10 Variation of saturation magnetization with mole % for (y) $Co_{1-x}Cd_xFe_2O_4$ + (1-y) PZT ME composites

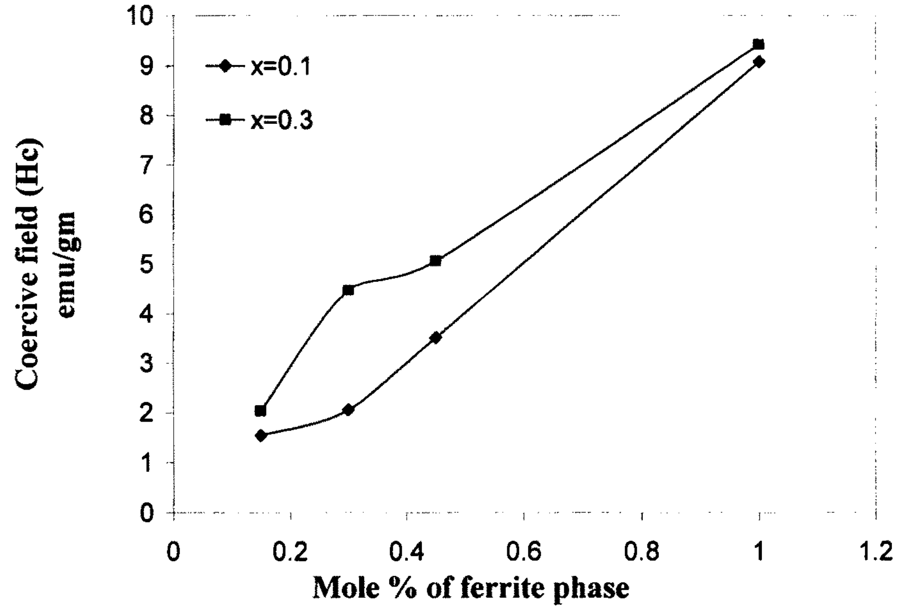

Fig.4.11 Variation of saturation magnetization with mole % for (y) $Co_{1-x}Cd_xFe_2O_4$ + (1-y) PZT ME composites where

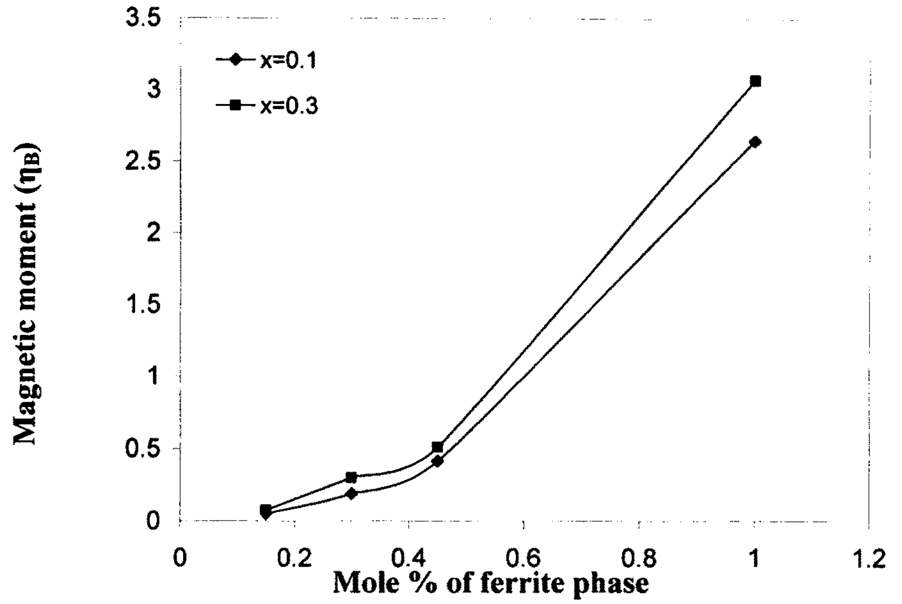

Fig.4.12 Variation of saturation magnetization with mole % for (y) $Co_{1-x}Cd_xFe_2O_4$ + (1-y) PZT ME composites

Tablel. Data of magnetic parameters for (y) $Co_{1-x}Cd_xFe_2O_4$ + (1-y) PZT ME composites where x = 0.1 and 0.3

(y)$Co_{0.9}Cd_{0.1}Fe_2O_4$ + (1-y) PZT ME composites			
Composition (y)	**Ms**	**Mr**	**η_B**
1	52.04	9.07	2.64
0.15	6.52	1.54	0.04
0.30	12.55	2.05	0.18
0.45	18.18	3.51	0.41
(y)$Co_{0.7}Cd_{0.3}Fe_2O_4$ + (1-y) PZT ME composites			
1	58.20	9.42	3.07
0.15	9.66	2.03	0.07
0.30	19.02	4.47	0.30
0.45	21.58	5.06	0.51

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