CHAPTER – 7

Summary & Conclusions

7.1 Summary

The present investigation on magnetic properties of tetravalent, trivalent, divalent or monovalent substituted Fe_3O_4 nanoparticles indicated that the variation of M_S values of Fe_3O_4 depends upon the type of substituent and their concentrations. Upon substitutions of tetravalent, trivalent, divalent and monovalent ions, the heating ability of Fe_3O_4 nanoparticles varied. Further, these samples show T_S values in the therapeutic range (42-46 °C) at suitable frequency and amplitude of AC magnetic fields. The T_S values achieved by various MNPs at different fields during MHT are listed in table 7.1. The obtained T_S values were not directly related on the type of substituent and it was observed with all monovalent, diavalent, trivalent or tetravalent ions substituted Fe_3O_4 samples. Further, for same types of substituent, the T_S values were independent of concentrations of the substituent. Some of the materials exhibited continuous rise in temperature during MHT at one set of applied magnetic field whereas T_S values at another fields. In contrast, few materials displayed continuous rise in temperature and some of them exhibited T_S values at all applied fields. As the exact reasons for this phenomena are not found and hence it needs more exclusive research. However, such materials may be useful in controlled hyperthermia, theranostic and drug delivery without causing significant damage to the healthy tissues.

Table 7.1: Temperature achieved by MNPs at different fields and frequency during MHT.

(x values)	9 mT, 640 kHz	23 mT, 173 kHz	25 mT, 112 kHz	23 mT, 260 kHz	17 mT, 337 kHz	11 mT, 478 kHz	17 mT, 170 kHz	17 mT, 733 kHz	24 mT, 521 kHz
(a) $Zr_xFe_{3-x}O_4$									
0.01	CRT	57	CRT	Experiment not done	CRT	CRT	Experiment not done		
0.02	CRT	CRT	43		CRT	CRT			
0.04	40	29	47		53	31			
0.05	CRT	CRT	55		CRT	CRT			
0.06	CRT	33	37		36	CRT			
0.07	CRT	CRT	43		CRT	40			
0.1	48	31	CRT		CRT	CRT			
0.2	CRT	CRT	CRT		CRT	CRT			
0.4	CRT	CRT	CRT		CRT	CRT			
0.5	CRT	39	CRT		CRT	CRT			
0.6	43	CRT	CRT		CRT	36			
0.7	CRT	CRT	CRT		CRT	58			
0.9	CRT	CRT	CRT		CRT	32			
1	47	40	CRT		CRT	CRT			
(b) $Hf_xFe_{3-x}O_4$									
0.05	35	37	38	Experiment not done	50	38	Experiment not done	49	Experiment not done
0.08	49	33	CRT		CRT	49		33	
0.2	45	50	CRT		CRT	38		52	
0.4	36	39	CRT		CRT	34		42	
0.6	CRT	CRT	CRT		CRT	CRT		CRT	
0.8	CRT	CRT	CRT		CRT	CRT		41	
(c) $Al_xFe_{3-x}O_4$									
0.01	46	CRT	CRT	CRT	CRT	CRT	37	Experiment not done	
0.07	CRT	CRT	CRT	CRT	CRT	CRT	43		
0.5	31	43	CRT	37	CRT	CRT	CRT		
0.7	31	28	32	31	42	34	32		
1	43	45	CRT	CRT	52	53	CRT		
(d) $Zn_xFe_{3-x}O_4$									
0.01	60	CRT	CRT	CRT	CRT	46	45	Experiment not done	
0.07	50	CRT	CRT	CRT	CRT	42	29		
0.2	52	CRT	CRT	CRT	CRT	CRT	40		
0.4	56	CRT	CRT	CRT	CRT	36	36		
0.8	30	30	30	30	30	34	28		
(e) $Li_xFe_{3-x}O_4$									
0.06	Experiment not done		CRT	CRT	CRT	CRT	Experiment not done	CRT	CRT
0.1			25	25	50	40		36	26
0.3			18	25	26	20		29	26

CRT = Continuous rise in temperature during MHT.

7.2 Conclusions

The major conclusions drawn from the present investigation are

- The M_S values of tetravalent doped magnetite ($M_xFe_{3-x}O_4$, M = Zr or Hf) nanoparticles were continuously varying with respect to substituent concentration. This was due to the substitutions of Zr^{4+}or Hf^{4+} ions at the tetrahedral and octahedral sites. The ferrofluids of these samples had displayed temperature stability (T_S ~ 42 – 46 °C) during MHT.
- The trivalent doped magnetite nanoparticles such as $Al_xFe_{3-x}O_4$ ($0.01 \leq x \leq 1$) samples also shown stabilization of temperature (T_S ~ 43 – 46 °C) at different combinations of frequencies and fields during hyperthermia.
- Due to the occupancy of Zn^{2+} and Fe^{2+} ions at tetrahedral sites of spinel structure, the M_S value for $Zn_xFe_{3-x}O_4$ ($0.01 \leq x \leq 0.8$) samples initially rose slightly and then decreased with increased Zn content. Like, tetravalent or trivalent substituted magnetites, Zn substituted samples also displayed AC field dependent controlled heating during MHT.
- The monovalent ions (Li^+) substitution has continuously decreased the M_S value of magnetite due to the occupancy of the Li-ions in octahedral sites of Fe_3O_4. All the samples exhibited T_S values which were in the range between 18 and 50 °C. All the T_S values did not lie in the range of therapeutic temperature (42 to 46 °C) like tetravalent, trivalent and divalent substituted magnetite samples.

7.3 Future scope of the work

- One may also investigate whether T_S values are also achieved for the Fe_3O_4 samples substituted by other ions like Mn, Co, Ni etc.
- The exact reasons for obtaining such T_S values may also be investigated.
- The *in-vitro* or *in-vivo* studies may be conducted to see whether these materials show T_S values during such experiments. These studies will also suggest about their biocompatibility.
- After finding positive results from the above studies, the materials may be used for clinical trials.