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SUPER-PARAMAGNETIC CARBON COATED IRON NANOPARTICLES AND BIOLOGICAL MAGNETIC INDUCTION HEATING PROPERTIES

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A new kind of magnetic induction heating materials-carbon coated iron nanoparticles(CCINS) was prepared by arc method and they were used for cancer therapy. The measurement of nanomaterials revealed that they are super-paramagnetic and exhibit a very strong induction heating ability.The magnetic induction heating property was measured by the conduction by Bio-heat method. Heating effect of pig liver injection method indicates that increasing the quantity of nanoparticles used, leads to higher iron content of nanoparticles and higher temperature. Magnetic induction heating effect of the pig liver was compared in the case of filling method with the injection method. The quantity of iron nanoparticles has a significant effect on the pig temperature in the case of injection method, while it has almost no effect in the case of filling method.

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Keywords: Super-paramagnetic; Cancer therapy; Carbon coated iron nanoparticles; Magnetic induction heating

1. Introduction

There is a strong interest in the potential utilization of magnetic nanoparticles in biomedical and magnetic targeting induction heating[1]. Targeting magnetic induction heating technique is a novel technique of tumour treatment[2,3]. In this procedure, the magnetic particles are injected into tumours and are subjected to an alternating magnetic field for magnetic induction hyperthermia, generating enough temperature to kill cancer cells[4,5]. Goal's research shows that normal cells and cancer cells are very different in high temperature[6]. Cancer cells are sensitive to temperature and will be killed at 42℃, while normal cells are still alive at 45℃. Therefore, when temperature of the tumour is over 42°C, the tumour cells may be destroyed.

Carbon coated iron nanoparticles are a new type of nanomaterials[7]. These particles have a core - shell structure with a metal or metal carbide core and carbon or graphite outer layer. Due to packaging by carbon layers, these nanoparticles are not be oxidized and hydrolyzed when exposed to the air[8]. The physical and chemical properties of the materials might change largely because of encapsulating materials into multi-walled carbon cages[9]. Due to nano effects, the properties of carbon-coated magnetic nanoparticles may be different from those of the corresponding magnetic nanoparticles[10].

We prepared carbon coated iron nanoparticles by carbon arc method. The carbon shells of

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the nanoparticles are porous, which makes carbon shells to have good drug adsorption properties. The iron cores have a high magnetic targeting ability and electromagnetic wave absorption ability, so on account of being wrapped by carbon shells, the iron particles are able to anti-oxidate. Carbon coated iron particles are more stable than iron particles. In this paper we mainly study this new kind of nanomaterial-carbon coated iron particles and test it's biological magnetic induction heating performance.

2. Experiment

2.1 Procedure

Carbon coated iron particles were prepared by carbon arc method. In brief, cathode was pure graphite rod, while the anode was a mixture of powders in different proportions Fe powder and graphite powder; High purity argon was protection air, pressure was 50 kPa; discharge current was 150A, voltage was 22V. After reaction, products on the combustion chamber wall were collected by a brush and consequently washed by methyl benzene. The remainder was carbon coated iron particles.

2.2 Characterization

A X-ray diffraction(XRD) with Cu（Kα） radiation was used at room temperature to identify the phase and the crystal structure. The micro-structure of carbon-coated iron nanoparticles was observed by using transmission electron microscope (TEM)(JEM-2010 HR) operating at 200Kv. Magnetic properties at room temperature of the products were characterized by a vibrating sample magnetometer (VSM), at magnetic field of -12-+12KOe. Magnetic induction heating effect was tested by using a high frequency alternating magnetic power source, the testing current of this power source was 300-600A.

3. Results and discussion

3.1. Structure and morphology of carbon-coated iron nanoparticles

Fig.1 shows the XRD patterns of different content iron carbon-coated iron nanoparticles, (iron content in the samples is 20%, 40%, 60%, and 80% respectively). In the diagram, the products only have carbon and iron peaks, so we do not find iron carbide and oxide diffraction peaks, indicating that the carbon-coated iron nanoparticles do not contain iron oxides and carbides.

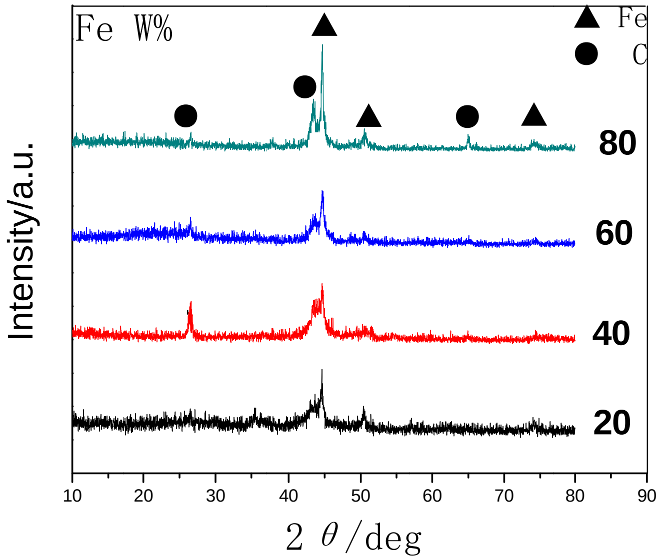

Fig.1. XRD patterns of different content iron carbon-coated iron nanoparticles

Fig.2 shows TEM image of carbon-coated iron nanoparticles, which reveal the general morphology, a typical core-shell structure of the nanocapsule materials. Nanoparticles are spherical particles with a diameter of 20-40 nm, the particle sizebeing fairly uniform. The core (dark part) is composed of metal iron, while outside (light part) are carbon layers.

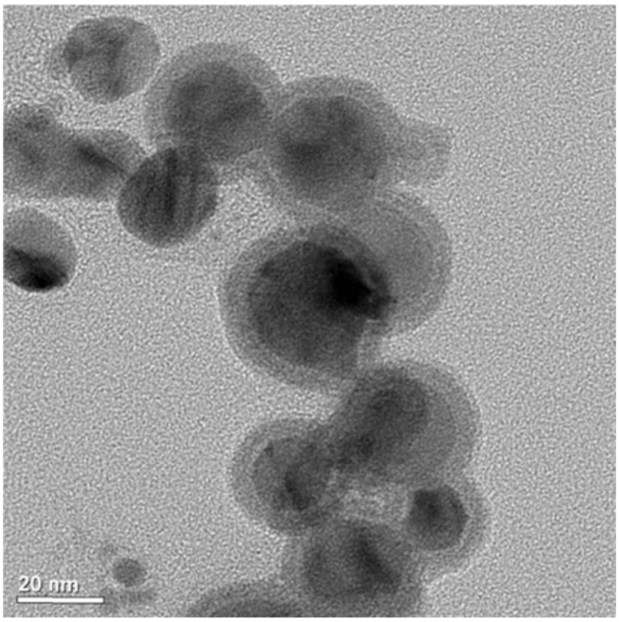

Fig.2. TEM images of carbon coated iron nanoparticles

3.2. Magnetic property of carbon-coated iron nanoparticles

Carbon-coated iron nanoparticles have potential applications as magnetic induction materials and this is why it is useful to study the magnetic properties of the sample. The hysteresis loops at room temperature of carbon coated iron nanoparticles (Fig.3) show that the saturation of samples magnetization increases with increasing the iron content, and at the same time the remanent magnetization and intrinsic coercivity also increase with the iron content increase. For the sample with 20% Fe, the saturation magnetization is 75.46 emu/g, remanent magnetization is 8.48emu/g, and intrinsic coercive force is 95 Oe, while the saturation magnetization, remanent magnetization and intrinsic coercive force for the sample with 80% iron content are 146.8emu/g, 19.35 emu/g and 307.3 Oe respectively.

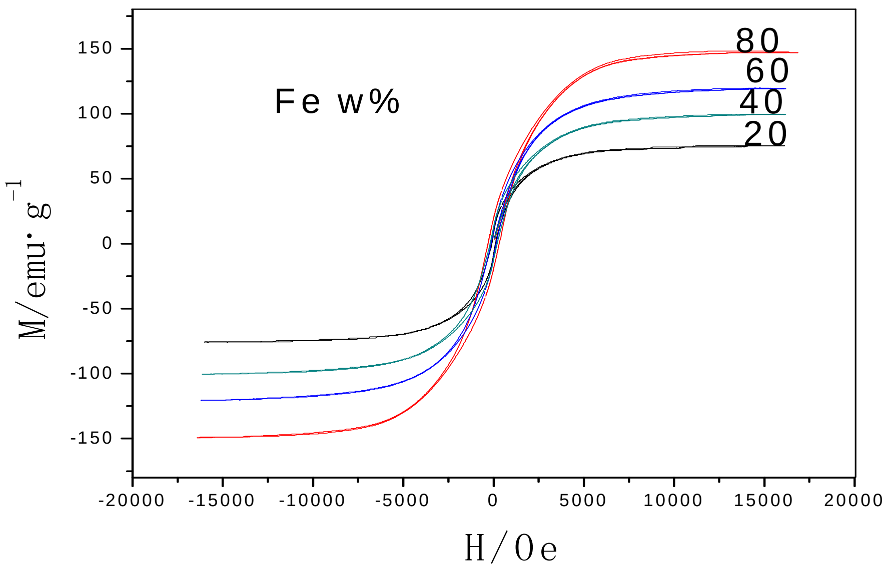

Fig.3. Magnetic field dependence of magnetization of different content iron carbon coated

The magnetic properties of materials could be valued by ratio of remanent and saturation(Mr/Ms). Mr/Ms of the iron content of 20% and 80% samples is 0.11 and 0.13. Mr/Ms less than 0.25[12] which is the value for the paramagnetic materials, so the carbon-coated iron nanoparticles are super- paramagnetic materials.

3.2 Effect of Pig liver magnetic induction heating after being injected suspension of physiological saline and carbon coated iron nanoparticles

0.3g and 0.15g carbon coated iron nanoparticles (Fe content is 40%) were dispersed into 2ml physiological saline respectively, then the suspension was injected into pig liver. In Fig.4 is shown the relationship between time and temperature. Fig. 5 shows the pig liver magnetic induction heating effect curves after injection of 0.075g/ml nanoparticles suspension, with particles having different Fe content of 40%, 50% and 80% respectively).

Fig. 4 shows magnetic induction heating effect of pig liver, which was injected different concentration of 40% Fe carbon coated iron particles and physiological saline suspension. From the curves we can draw a conclusion that the higher the particle concentration was, the faster the pig liver temperature increased. By contrast, we put pure physiological saline into alternating magnetic field, and we observe that it has no induction heating effect. In Fig. 5 is the pig liver magnetic induction heating effect curve, when the liver was injected with different Fe containing carbon coated iron particles suspension (concentration 0.075g/ml). In the initiation stage, the 40% and 50% Fe particles suspension have the same temperature increase rate, and after 20 min the one with 40% Fe (by content) almost doesn't increase and enters into a temperature stable stage. On the other hand the 50% Fe containing suspension temperature increases continually in all stages. It is obvious that the higher Fe content, the higher the suspension temperature increases. After 30 minutes of magnetic induction heating, the sample with 40% Fe content reaches 42℃, the 50% Fe sample reaches 44℃ and the 80% Fe sample reaches 51℃. At 42 ℃ the tumour cells will be destructed. The carbon coated iron particles magnetic induction heating temperature can reach more than 50 ℃, and this temperature is enough to kill tumour cells.

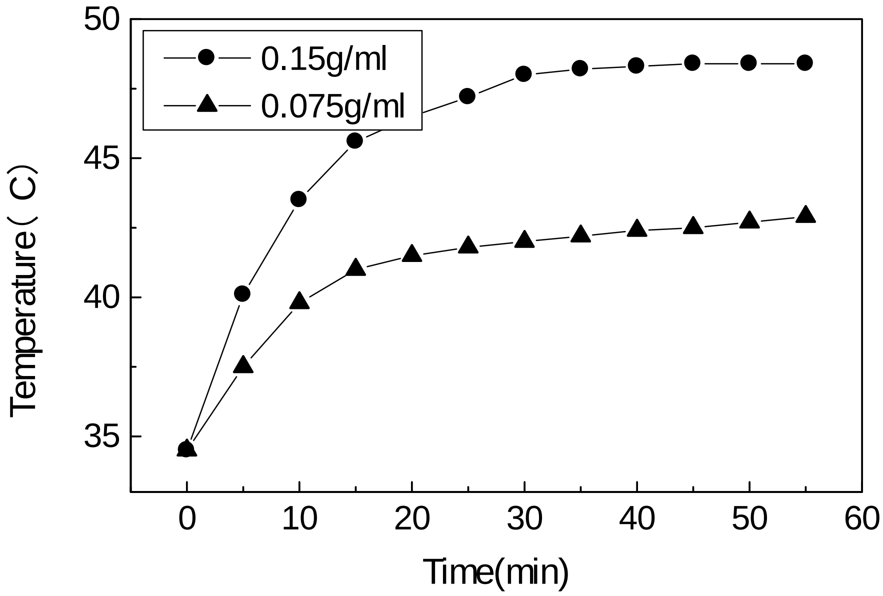

Fig .4 Magnetic induction heating curves of pig liver injected different concentration

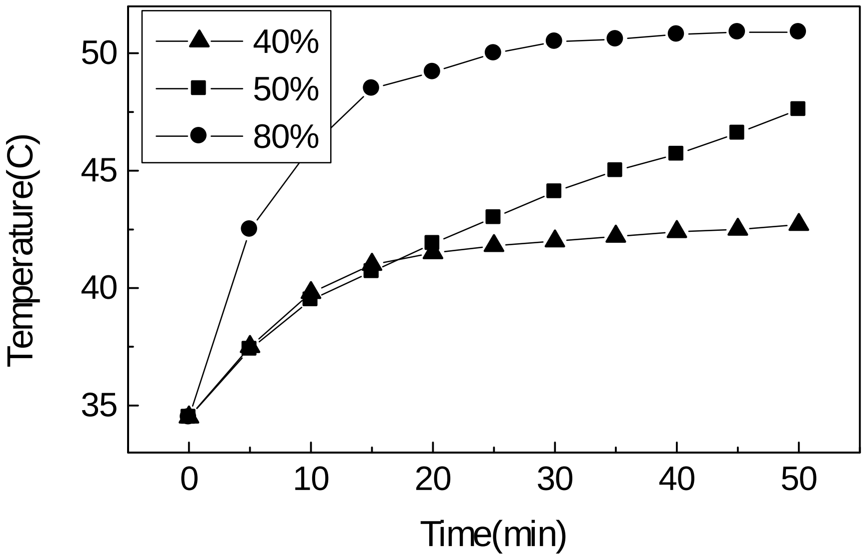

Fig. 5 Magnetic induction heating curves of pig liver injected 0.075g/ml carbon coated iron nanoparticles with different Fe containing and physiological saline suspension

3.3 Different position of pig liver magnetic induction heating effect after being injected suspension of physiological saline and carbon coated iron nanoparticles

Suspension of 0.075g/ml, 40% Fe containing carbon coated iron nanoparticles and physiological saline and 0.15g/ml, 40% Fe containing carbon coated iron nanoparticles and physiological saline were injected into pig liver. Then was measured the temperature in different parts of the pig liver. In Fig .6 is depicted the 0.075g/ml sample and in Fig .7 is the 0.15g/ml sample. As it was illustrated in the graph the temperature changed in different parts of the pig liver. When the suspension was injected into pig liver, the particles concentrated in the middle of the organ. They are confined in the injection area by the magnetic field. So the temperature was higher in the middle of the liver than on the surface. The 0.15g/ml suspension can heat the middle of the liver to 48℃, while the surface was only 33℃. Therefore, the magnetic field doesn't affect the part of the organ without carbon coated iron particles, so this nanomaterial was capable of killing tumour cells meanwhile the normal cells can avoid being hurt.

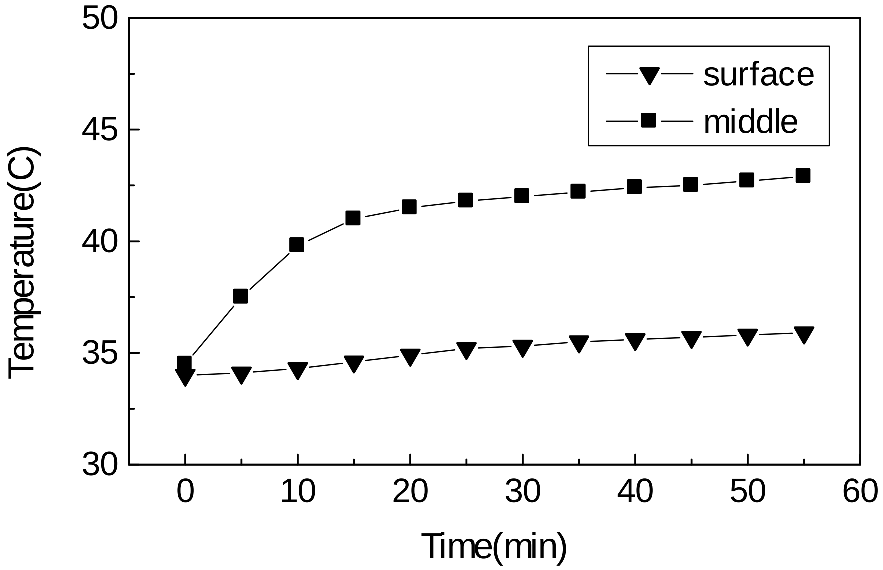

Fig .6 Different position magnetic induction heating effect of pig liver after being injected 0.075g/ml 40% Fe containing suspension

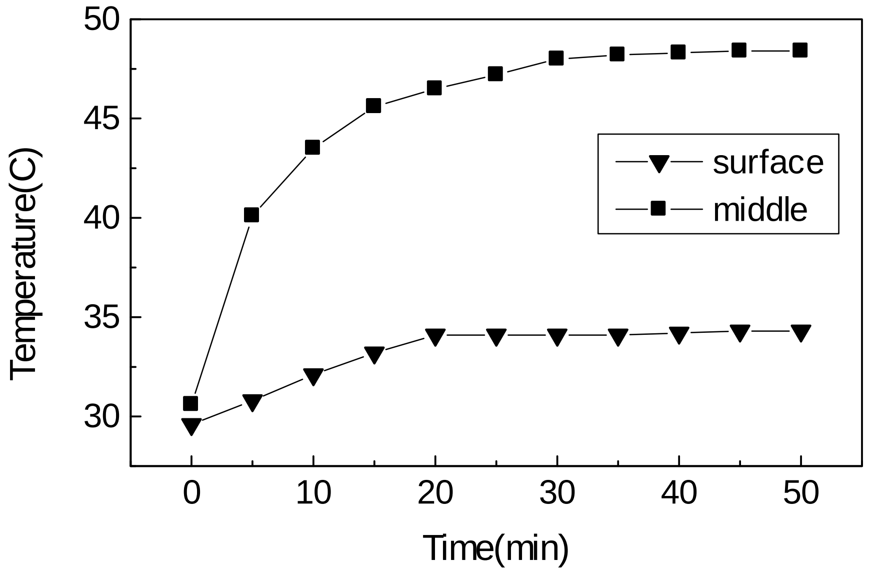

Fig .7 Different position magnetic induction heating effect of pig liver after being injected 0.15g/ml 40% Fe containing suspension

3.4 Effect of Pig liver magnetic induction heating after being filled with carbon coated iron nanoparticles

A hole was bored in the pig liver then carbon coated iron nanoparticles filled in the hole. Then this sample was put into magnetic alternating field. The sample temperature was tested by a thermometer. In Fig. 8 are pig liver magnetic induction heating temperature change curves, and they show that 0.1g carbon coated iron particles can heat the pig liver to 42℃, at the same time, the more particles being used, the higher temperature the pig liver was, but the difference was not very remarkable. The reason was that the particles that filled in the pig liver were not easy to disperse into the organ. All the particles gather round the filling area, and the induction heat was not easy to transmit to pig liver surface. So there are not too much temperature differences among these 3 curves.

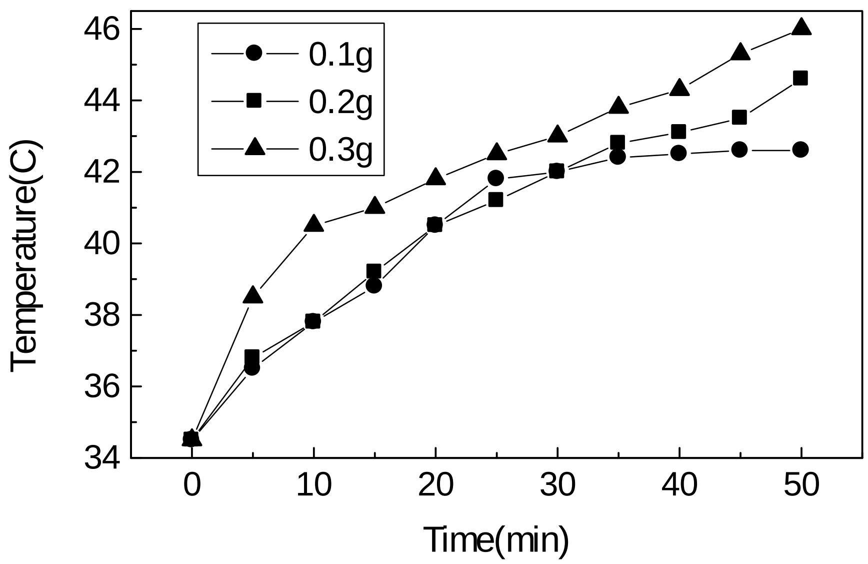

Fig .8 Magnetic Induction heating effect of pig liver filled different weight carbon coated iron particles (containing 40% Fe)

4. Conclusions

In summary, carbon coated iron nanoparticles are a new type of magnetic induction heating materials, theyhave a core-shell structure and the iron nanoparticles are fully coated by nano carbon layers. Hysteresis loops show that as-made materials have good superparamagnetic properties, and with the increase of iron content their magnetic properties are enhanced. The carbon coated iron nanoparticles can be both induction heating sources and magnetic targets for delivery in tumour therapy. The influencing factors of induction heating effect are as follows: (1) Quantity of drug carrier: the more carbon coated iron nanoparticles being used, the higher the temperature was. (2) Quantity of magnetism materials in particles, high containing of Fe particles have better heating effect than the one of low Fe containing. (3) Time of induction heating, the temperature will increase with the extension of induction heating time, finally it will reach a stable temperature stage. (4)The putting method of drug carrier particles : injection method is better than filling method.

Acknowledgements

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