

Benefits of Purpose-Built Nanoparticle Heating Systems Over Conventional Induction Heaters

What is the difference between induction heating and magnetic nanoparticle heating, and why should induction heaters be avoided for studying power loss (heating profile) of magnetic nanoparticles in AC magnetic fields?

Electromagnetic induction is a phenomenon of voltage production in a conductor when it is brought close to a time-varying magnetic field. In Induction heating, this electromagnetic induction principle is used to heat any matter with electrical conductivity due to joule heating (or resistance heating) as the induced current flows through the material.

An induction heating system consists of a solenoid coil, through which a high-frequency alternating current is passed, producing a magnetic field. Heat may also be generated by hysteresis losses in materials that have significant relative magnetic permeability. The frequency of the AC used depends on the object size, material type, coupling (between the work coil and the object to be heated) and the penetration depth. Induction heating allows the targeted heating of any conductors in a solid, liquid or gaseous state, and is mostly used for preheating, post heating, straightening, tempering, hardening, annealing, bonding, melting, brazing, soldering, heating and welding applications.

Magnetic materials respond better to induction heating due to their magnetic properties. Eddy currents will be generated in any conductor, but magnetic hysteresis losses also occur in magnetic materials, thus the induction heating is more efficient in materials with high magnetic permeability. A typical induction heating setup has a power supply that provides electricity with a very high current and a narrow frequency range. The work piece is positioned within a solenoid driven by the power supply, and the setup heats the work piece by producing eddy currents in the work piece.

Application frequency in an induction heater varies from a few tens of kilohertz to a few hundred kilohertz, depending on the size of materials.



Figure 1. A non-ideal commercial induction heater

Drawbacks of Conventional Induction Heaters for Nanoparticle Heating

Commercially available or DIY induction heaters should not be used for studying the heating properties of magnetic nanoparticles designed for biomedical applications or in vitro/in vivo experiments in laboratory conditions for the following reasons:

1. Eddy current heating

Induction heating setups are designed exclusively to generate a high amount of eddy current, whereas research articles discuss the fact that the heating of magnetic nanoparticles due to eddy currents is negligible.

Additionally, based on some super paramagnetic iron oxide samples which showed a high heating profile, the increase in heating was mainly due to Neel and Brownian relaxation losses as their hysteresis loops were very narrow (based on actual M-H curve measurements). High heat dissipation of magnetic nanoparticles heavily depends on the relaxation losses rather than wider hysteresis loops and eddy currents.

2. Excessive exposure

Induction heaters typically do not obey the limits of safe exposure of time varying magnetic field strengths involved in biomedical applications, as they pass high amounts of current through the solenoid to induce eddy currents. Atkinson et al concluded that exposure to fields where the product $H_0 \times f$ does not exceed $4.85 \times 10^{-8} \text{ Am}^{-1} \text{ s}^{-1}$ is safe and tolerable.

3. Limited frequency range

Most importantly, commercially available induction heaters do not have a very wide frequency range capability – typically from 150 kHz to maybe 450 kHz.

This means that for the researcher studying the heating profiles of nanoparticles with varying size, shape, magnetisation, coating, etc., there is a great chance that the optimal heating frequency will be missed – without the capability to generate a full Frequency Response Profile, a nanoparticle may be dismissed as being not suitable for hyperthermia applications when in fact at the correct frequency it proves ideal.

4. Insufficient containment

External coils without proper containment are not appropriate to perform calorimetric, in vitro/ in vivo experiments, from a health and safety, biological sample contamination hazard, and ethical point of view.



Figure 2. magneTherm's internal coil



Figure 3. magneTherm's set up with insulating jacket

5. Non-adiabatic heating

Researchers have demonstrated that the setup to perform calorimetric experiments in magnetic nanoparticles requires excellent thermal heating to prevent non-specific heating from the environment, especially from the coil. Comparison of calorimetric experiments in magnetic nanoparticles between an appropriate setup such as the magneTherm and the usual induction heating setup revealed that there was more than 21% deviation in SAR values due to non-adiabatic heating with a typical induction heater setup.

6. Insufficient sample positioning

Usual induction heating setups, in addition to the absence of an adiabatic shield, neither provide proper insulation for the sample, nor facilitate appropriate positioning of the sample, which is essential when performing replicable calorimetric / in vitro / in vivo experiments.

Sample positioning is very important, because a well-designed coil will take into account high field intensity and homogeneity within the coil, so when positioning the sample within the coil it is very important that the whole sample should experience uniform field strength.

Sample positioning in coils with different number of turns

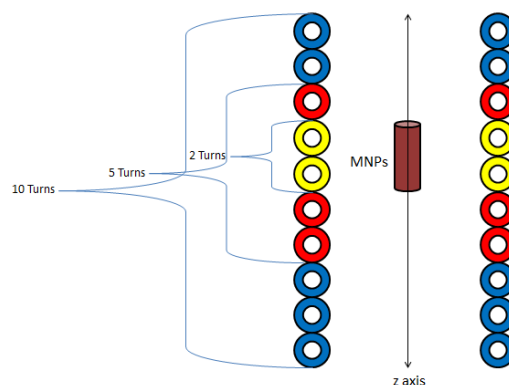


Figure 4. Shows Sample positioning considerations for magnetic fluid hyperthermia and calorimetric experiment

7. Limited temperature monitoring capabilities

Induction systems also lack proper temperature measurement setups, i.e. a thermocouple, optical thermal sensors, or IR camera within a contained insulated area amidst an adiabatic shield. Since the main purpose of a calorimetric experiment is real-time measurement of temperature in the magnetic nanoparticles over time due to the AC magnetic field, this is a very important consideration.



Figure 5. Temperature sensing/ imaging systems compatible with magneTherm i.e. thermocouple with USB Digital Thermometer, fibre optical sensor, infra-red camera

8. No water jacket for sample temperature control

Like the adiabatic shield, a continuous water jacket with a well regulated flow rate becomes a must for in vivo / in vitro work, as it provides uniform temperature over the in vitro tissue sample or animal, and eliminates the inevitable non-specific heating when animals are exposed to high amplitude AC magnetic fields during magnetic fluid hyperthermia experiments. None of the commercially available induction heating systems have a water jacket.



Figure 6. magneTherm's water jacket set up for in vivo / in vitro experiments

9. Comparative experiments are not possible with single-frequency coils

Induction heaters use simple solenoids which don't provide a homogeneous magnetic field or pattern, so that the energy transfer from the solenoid coil to the magnetic nanoparticles is affected significantly by the distance between them.

When performing comparison experiments over a wide range of frequencies, a setup with a single standard coil is a must. If the coil geometry and parameters change for each frequency, as is common with some induction heaters where the only way to change the frequency is to change the complete coil, the users will not be able to compare the results from one coil to the next.

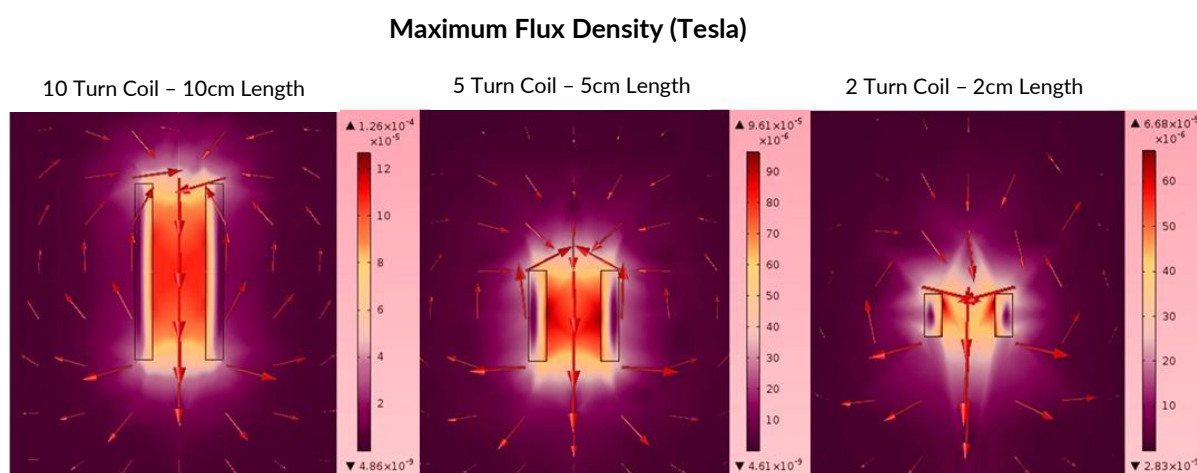


Figure 7. Magnetic flux density pattern in different coils with different number of turns and length

Nanותרics provide products addressing the field of magnetic nanoparticle research and applications. In particular we aim to be the number one supplier of products for nanoparticle heating applications utilizing AC field and solenoid coil principles.

Our aim is to provide superior performance magnetic based tools to address global markets and to underpin the research and development of current and future nanoparticle, magnetic particle, cancer therapy, drug delivery, genetic screening and gene therapy programs.


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