Abstract

The modern textile industry has experienced tremendous changes and become one of the best premier beneficiaries of advances in nanotechnology. This project is to explore the applications and management of nanotechnology to textile industry. The experimental studies include microwave absorption and magnetic induced heating on polyester textile using three magnetic nanoparticles -- Carbonyl Iron Powder (CIP), Magnetite (Fe_3O_4) and Ferrofluids. In comparison with the textile without applying magnetic nanoparticle material, these functional textiles show intersecting property of microwave absorption in the particular range of frequency and magnetic induced heating. I call these two promising textiles -- Microwave-Absorption Textile (MAT) and Magnetic Heated Textile (MHT).

Despite I have achieved significant and interesting results on MAT and MHT, there is plenty of work to be done not only in the development but also in the commercialization of the textiles. Thus, the public health and environmental safety become extremely important because there are a large number of imitators in the target market-China, and their lack of full knowledge, skills and understanding of the particular nanomaterials and nanoprocesses may result in the flood of counterfeit and poor-quality products in Chinese market which may endanger both public health and environmental safety. In order to minimize and manage the health and safety risks, I implement risk management for nanotechnology using two models -- National Innovation System (NIS) and Intellectual Property Rights (IPR), and significant findings are obtained. First, I find that a NIS can help nanotechnology manage health and safety risks in the development and commercialization of products with three stages: innovation inputs, innovation process and innovation outputs. Second, I find that IPR can be a good model for risk management, with which the risks associated with public health and environmental safety can be controlled, and those people or

organizations that use our products without authorisation can be detected, and the violations of property rights and illegal imitations can be prevented.

Chapter 1 introduces nanotechnology, risk management and the functional textiles. Chapter 2 reviews literature on the applications of functional textile using nanotechnology and the applications of nanofinishing and nanocoating. Chapter 3 introduces risk management principles and models, and I put the context in China which is the top player in the textile industries around the globe. Chapter 4 discusses the experimental work with the results from MAT and MHT. In Chapter 5 I apply the NIS and IPR models and discuss how to manage the risks associated with public health and environmental safety. Chapter 6 concludes and makes recommendations for future research.

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Chapter 1 Introduction

1.1 Nanotechnology

Nanotechnology literally means the technology applied in the real world on a nanoscale.[1] Nowadays, nanotechnology has been defined very broad, including a number of science as diverse as material science, surface science, organic chemistry, molecular biology, semiconductor physics, micro-/nano-fabrication, etc.[2] At the same time, the associated research on the material and devices approaches using nanotechnology from developing new materials on the nanoscale to atomic scale. Nanomaterials[3, 4] is one of the most promising research topics, such as drug delivery,[5] catalysis,[6] antibiotics,[7] cancer research,[8] fiber,[9] and so on.

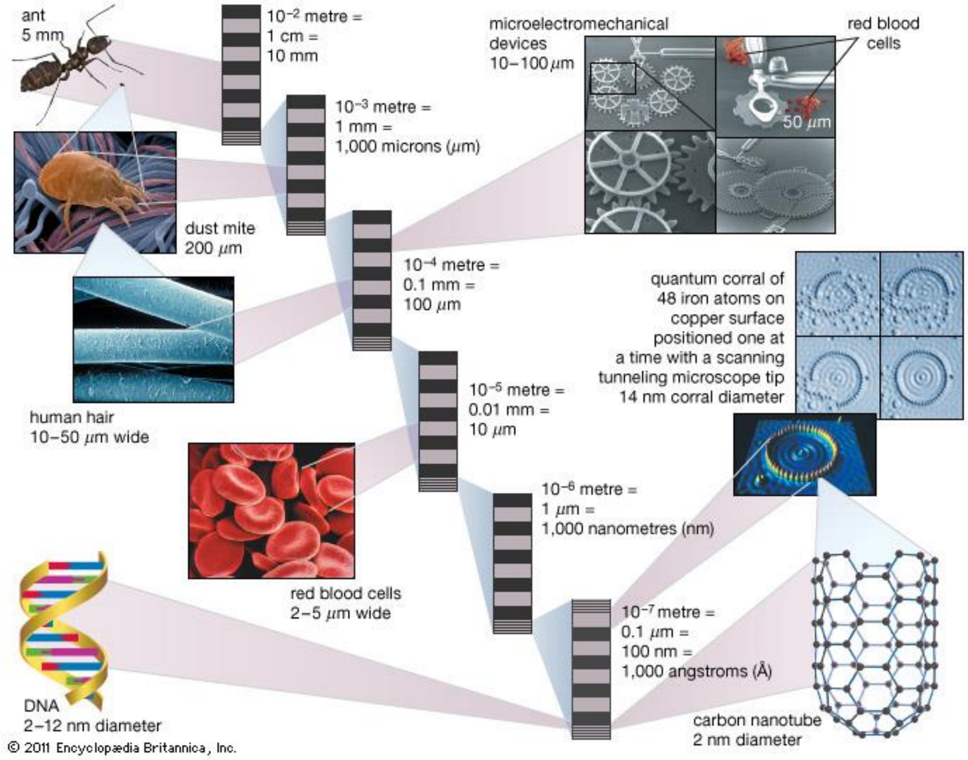

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Fig. 1 Scale from micrometer to nanometer dimensions. (Encyclopedia Britannica, Inc.)[10]

At the nanoscale, the physical, chemical, mechanical and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms/molecules or bulk matter.

1.2 Risk and Risk Management

Risk, defined as an uncertain consequence of an activity or technology, has two components – likelihood of potential consequence and the severity of the consequence.[11] The analysis of risk not only covers physical consequences but also includes financial impact, economic investments, institutions, cultural heritage and psychological impact.[12]

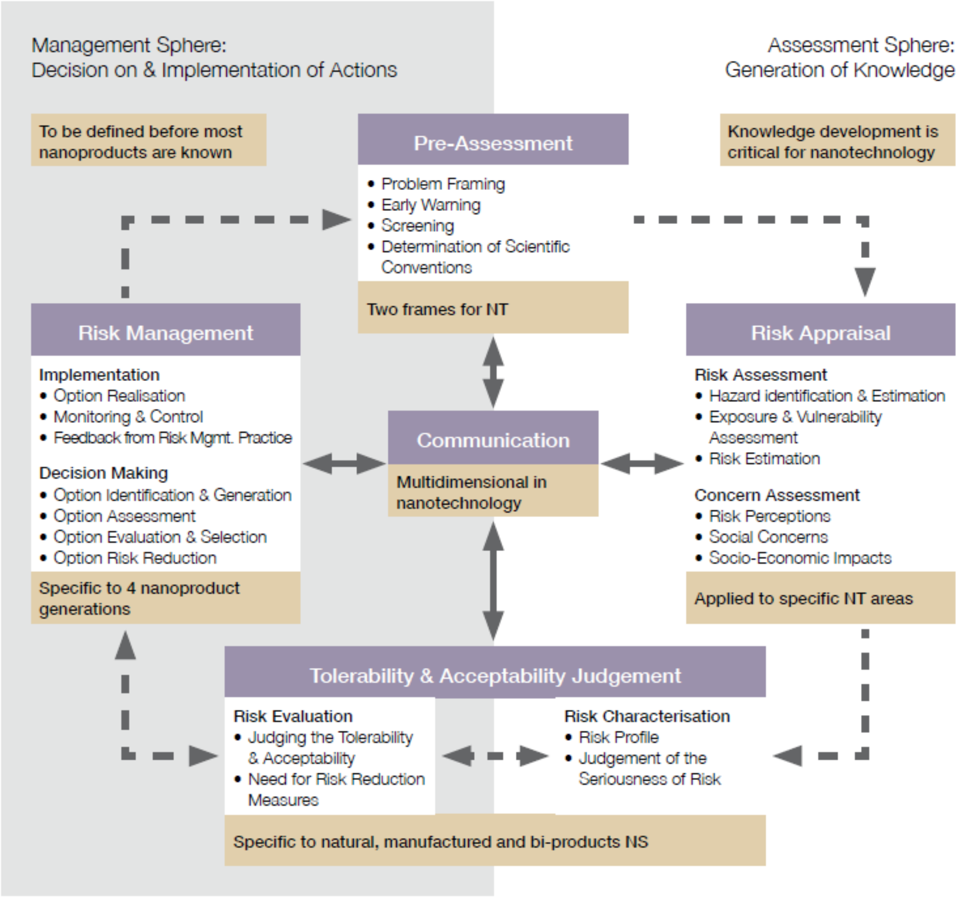


Fig. 2 International Risk Governance council (IRGC) Risk Governance framework (White Paper on Risk Governance – Towards an Integrative Approach)[13]

The above figure shows an integrated framework taking into account scientific, economic, and social aspects of all stakeholders concerned while analysing the risk and hazards, by the International Risk Governance council (IRGC), an independent foundation. The framework has two main parts: (1) Management Sphere, which obtains decision on and implementation of actions; (2) Assessment Sphere, which obtain generation of knowledge; and also are divided into 5 sections: (1) Pre- Assessment, (2) Risk Appraisal, (3) Risk Management, (4) Risk Communication, (5) Tolerability & Acceptability Judgement. In this thesis, we will focus on the importance of Risk Management and the relationships between Risk Management and the nanotechnology.[14.]

Risk Management is very important strategy to manage technology development and product introduction to the market place based on public demand within the safety standard of health and environment. Generally, risk management aims to tackle the hazards to society by setting out measures for avoiding, preventing, reducing, transferring or self-retaining risks, including to develop the testing methods and to identify the best metrics for toxicity and ecotoxicity.[15, 16]

Another strategy of risk management for nanotechnology is to standardise the process of technology development by the development of relevant nomenclatures, novel processes and products. It allows risk management to start the re-market testing for health and environmental impact, life cycle assessment and consideration of secondary risks in order to help risk management reduce exposure risks, for example, using protective equipment in some way.[17, 18]In this thesis, we will introduce two types of models of risk management in order to manage the risks associated product introduction in the target market - China: National Innovation System (NIS) as one of the traditional risk management principles and Intellectual Property Right (IPR) as one of the precautionary risk management principle.

1.3 Functional Textile using Nanotechnology

Recently, the global textiles industry has been struggling to cope with reduced demand and downward price pressure driven by the current economic situation. Thus, it becomes more important for the textiles industry to fast up the development of the nanotechnology on the textiles as the major breakthroughs.

In the textile industry, nanotechnology is more likely to be applied to make new materials or improve the properties of existing materials, rather than to reduce the production cost or improve quality.

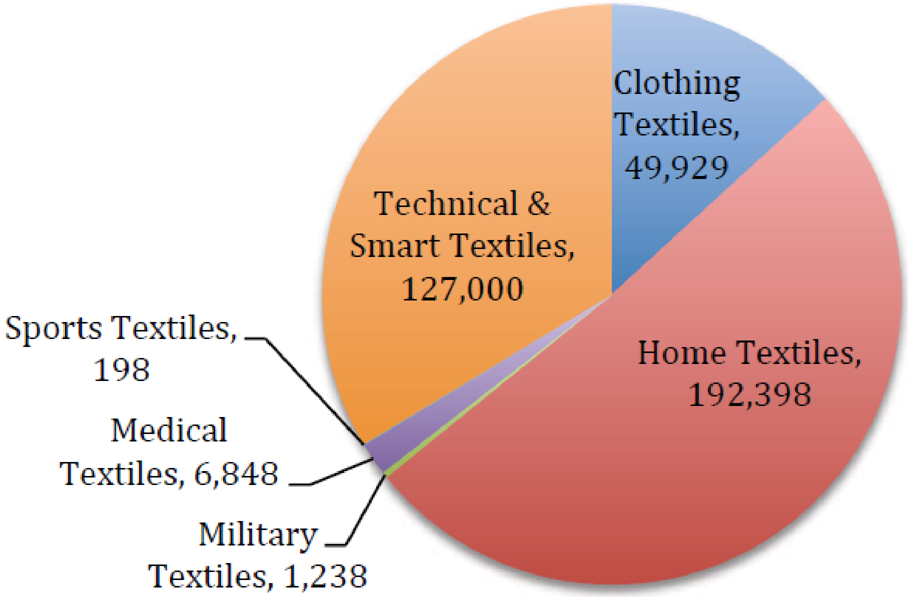


Fig. 3 The global textile market by section (in US$millions).[19]

The market for textile making use of nanotechnologies has increased quickly form US$ 20.3 billion in 2008 and is projected to reach US$ 29.8 billion by 2022,[19] as show in the below figures.

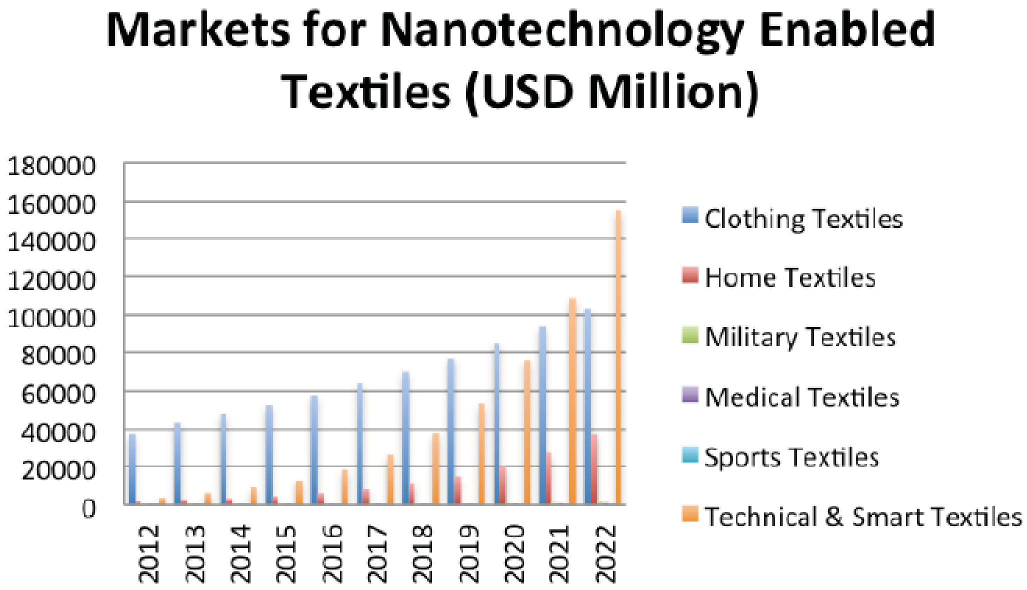


Fig. 4 Markets for nano-enabled textiles (in US$millions).[19]

Figure 4 shows the markets for the functional textiles using nanotechnology by sector. Currently nanotechnologies account for only 7.44% of the market for clothing, the largest sector in 2012, and this will increase to 16.78% by 2012 as new applications and the falling cost of nanomaterials increase market penetration. [19]

The use of technical textiles as functional textile tends to produce low cost and low weight products with better reliability in service and greater energy savings. The uses of nanotechnology in textile manufacturing have been increasing rapidly, which makes us show huge interest to study the nanotechnology used on the functional textile.

1.4 Outline of this thesis

In this thesis, we will first introduce nanotechnology, risk management and functional textile using nanotechnology in Chapter 1. We review the applications of functional textile in Chapter 2.

In Chapter 3, we also review the risk management for nanotechnology with Traditional Risk Management Principles and Precautionary Risk Management Principle, and the models -- National Innovation System (NIS) and Intellectual Property Right (IPR).

Chapter 4 describes the experimental principles, instruments and results from the practical part of this work. Three materials are used: Carbonyl Iron Powder (CIP), Fe_3O_4 (Magnetite) and Ferrofluids. Three types of measurements have been carried out to test the functional textiles: Arch Test for Radar Absorbing Materials, Electromagnetic (EM) Wave Shielding Effectiveness (WSE) Measurement and Magnetic Induction Hyperthermia (MIH) Measurement. Detailed experimental results and analysis will be presented. We study the risk management of NIS and IPR for the researched functional textiles Microwave-Absorption Textile (MAT) and Magnetic Heated Textile (MHT) and also in the important textile country--China in Chapter 5.

Finally the results are summarised and some suggestions for future work are proposed in Chapter 6.

Chapter 2

Nanotechnology for Functional Textile

2.1 Development of nanotechnology for functional textile

It has been well demonstrated in the recent years that nanotechnology can be used in manufacturing of the functional textile to enhance textile functions such as fabric softness, durability, and breathability, water repellency, fire retardancy and so on. Nanotechnology therefore shows significant promise in textiles.[20, 21]

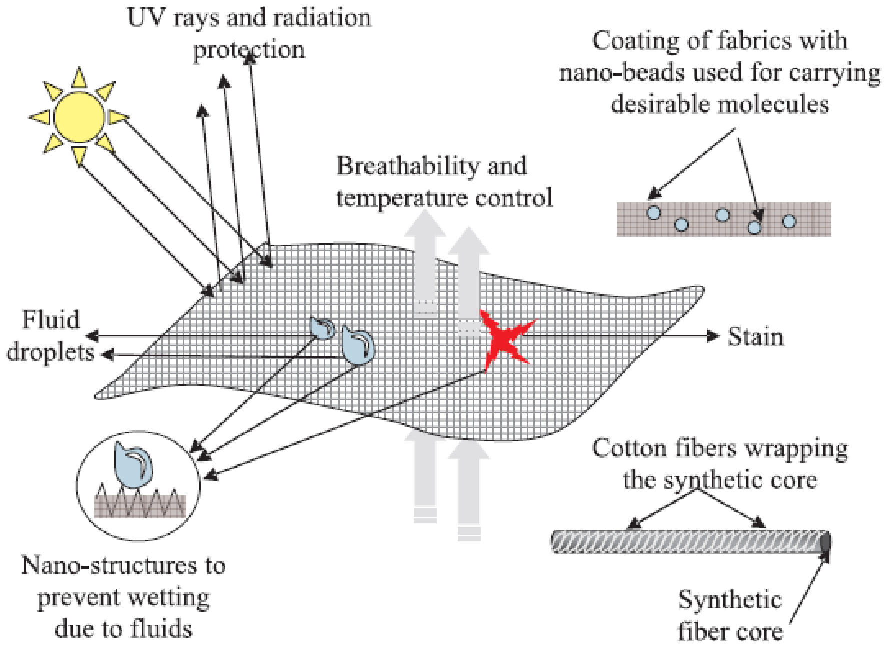


Fig. 5 Functional textile uses nanotechnology to enhance textile's properties and performance.[22]

Figure 5 shows a few representative applications of textile using nanotechnology to enhance properties and performance. Nanotechnology provides plenty of efficient tools and techniques to produce desirable textile, mainly by engineering modifications of the fabric surface. For example, Schrauth et al have demonstrated that by changing the micro- and nano-scale surface features on a fabric surface, a more robust control of wetting behavior for the textile is achieved, whose surface properties exhibit the "Lotus-Effect", which is a natural hydrophobic behavior of a leaf surface. This sort of surface engineering can be used in developing special chemical finishes for water-and/or stain-resistant fabrics.[23]

2.2 Applications of Functional Textiles using nanotechnology

The progress in research of Nanotechnology-based textile has led to the development of several new and improved textile products (Figure 6). Numerous references in the literatures have studied to highlight the various applications of nanotechnology for the textile industries.[24, 25]

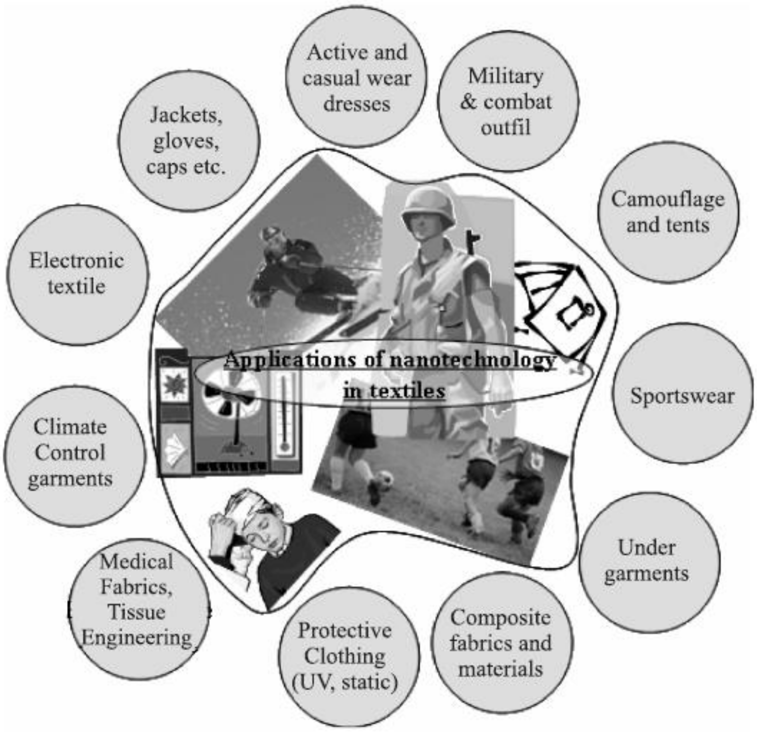


Fig. 6 Some representative applications of nanotechnology in textiles.[22]

Here, we introduce some applications of textiles using nanotechnology to achieve the functional textiles: Protection Applications, Reinforce Applications and Health Applications.

2.2.1 Protection Applications

The protection applications of the functional textiles using nanotechnology include: Antistatic or electromagnetic shielding; ballistic impact protection, fire protection and flame retardant textiles, UV blocking textiles, and so on.

(a). Antistatic or electromagnetic shielding

Antistatic or electromagnetic shielding functions in textiles can be achieved by a few nanotechnologies, such as increasing the conductivity of the fibers.[26] Synthetic textilepolymers, as for example polypropylene (PP) or polyethylene (PE), generally have a rather low electric conductivity and therefore act as isolators. In order to create a conductive material which still shows manufacturing favorable mechanical properties of the polymers, small metal particles, conductive polymers (e.g. polypyrrole, polyanilline, polythiophen) or also carbon nanoparticles (Carbon Nanotubes (CNT), Carbon Black (CB)) can be included into the polymer matrix [2728].

Recent developments in the electronics industry involving radio frequency (RF) devices, however, has one of the most major side effect of radio frequency which does effect on human beings' health.[29] There are mainly 5 aspects RF will have impact on human's bodies in long term:[30]

- nervus centralis
- immune system
- cardiovascular system

- reproductive system
- vision system

Table 1: NP, textile matrices and production methods reported in the examined research papers for conductive textiles. The last column shows the form in which the NP occur in the finished fabric.

NP / NC	Textile material	Production method	Integration into the textile matrix
Cu	PP/PA	physical vapor deposition: sputter coating[31]	Homogeneous Cu-layer, some nm thick
CB*	Polyurethane (PU)	electrospinning of PU dispersion with CB[28]	CB-nanoparticles in nm thin PU fibre
CNT	Not specified	dip or spray coating of finished textile[32]	Some SWCNT cluster on the fibre surface
	PP	dip-coating with polyaniline / CNT dispersion[33]	CNT in polyaniline matrix and as composite layer on and in PP hollow fibre
	-	wet spinning of dispersive CNT / polyaniline solution	Polyaniline CNT composite fibre
Polypyrrole	viscose, wool	vapor or solution polymerization of polypyrrole on the textile[34]	Homogenous layer of polypyrrole on the fabric, partial penetration of polypyrrole into fibre interior, Aggregates of polypyrrole on the fibre surface, complete penetration of polypyrrole into interior of fibre.
	wool	hand brushing , dip or spray coating of finished textile with a polypyrrole emulsion [35]	Non homogeneous, nanoporous polypyrrole layer
Polyaniline	polyester	Solution polymerization[36]	Polyaniline layer on PET fibre

(NP: Nano-particle; NC: Nano-structure) (*: in dispersion:400-1700nm)

Although this is not a rapid effect, it is indeed a problem which cannot be neglected. It does attract my interests to study this type of function textile in my research, to develop a kind of method or textile that has the function of efficiently absorbing or reflecting RF.

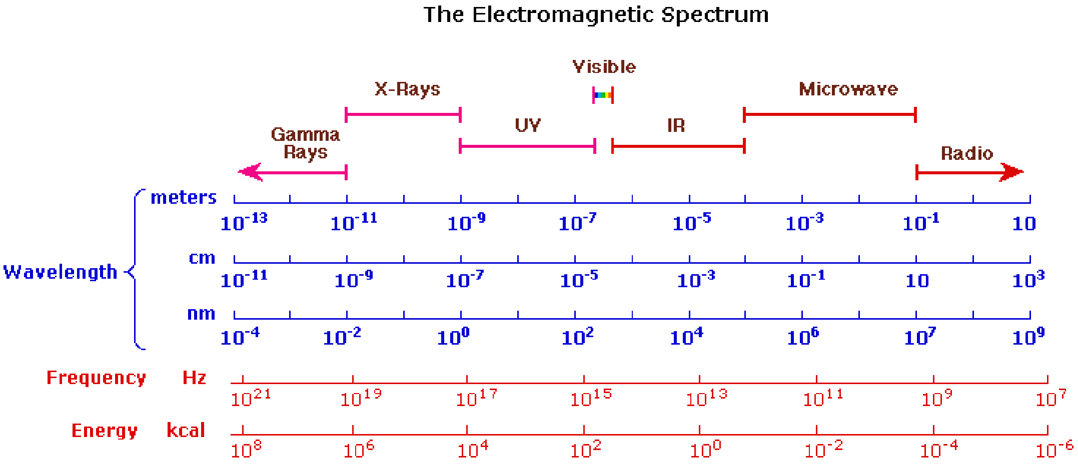


Fig. 7 The electromagnetic spectrum.[37]

This practical part will be divided into several parts: the fabrication of sample; RF related measurement; Analysis and amendment; Future work. This is a vital part in this dissertation. After the introduction of the existing functional textiles by nanotechnology, a series of textile samples would be fabricated to study antistatic or electromagnetic shielding.

(b). Ballistic impact protection

In recent studies, nanofibres have shown great potential to be used for ballistic protection.[38] One company is considering developing body armours by using a nanocomposite based on inorganic fullerenes (IF), which is twice as strong as any other impact-resistant material currently used, and five times stronger than steel.[39]

Carbon nanotube has great potential for making antiballistic materials due to its high strength, lightweight and excellent energy absorption capacity.

Mylvaganam and Zhang have investigated the potential of using carbon nanotubes against ballistic impact. They summarised from their study that body armour of only 600 μm in thickness, made from six layers of 100 μm carbon nanotube yarns, may bounce off a bullet with muzzle energy of 320J. They also mentioned that the ballistic resistance capacityis greater at the centre of a carbon nanotube, and a tube with a larger radius can withstand higher bullet speeds[40].

(c). Fire retardant textiles

Fire or Flame retardant protective textiles provide an opportunity for nanotechnology to take over the existing technology due to the health and environmental impacts of existing halogenated fire resistant materials. Wang et al have investigated the effects of nano-scaled layered double hydroxides (LDH) and nano-titanium dioxide to improve the fire resistance and anti-ageing properties of fire retardant coatings and found great improvements in the properties[41].

The integration of several kinds of nanocomposites has been found to produce flame retarding effects.[42]. Due to its low price, many research projects focused on the production of montmorillonite-nanoclay containing composites to achieve these properties [43-47], but also boroxosiloxanes or Sb_2O_3 containing nanocomposites were reported to inhibit the combustion process[42]. A further possible method seems to be the use of CNT which led to enhanced flame retardance when incorporated into an ethylene-vinyl acetate (EVA) polymer-matrix[48].

(d). UV blocking textiles

UV blocking textiles can be achieved by coating textiles with nano-sized particles of zinc oxide or titanium oxide. Xin *et al* have applied a thin layer of titanium oxide on cotton fabrics by using the sol-gel method, and have achieved good UV blocking properties of treated fabrics even after 50 home launderings[49].

The UV blocking properties of textiles can also be improved by the integration of metal nanoparticles like TiO_2, ZnO and Fe_2O_3 as the application of a UV-absorbing finish to the fabric,[50, 51] or by coating the cotton fabrics with a nanoparticles TiO_2 film by sol-gel-process using the dip-pad-dry-cure method.[52]

2.2.2 Reinforce Applications

(a). Oil-repellent, water-repellent, stain-repellent textiles

In order to generate oil and water repellent surfaces in cotton, low surface energy materials are used, such as fluorocarbon containing or non-fluorocarbon-based finishes.[53]

In sports and outdoor applications, the breathability and comfort of clothing is in high demand, along with water, soil and oil proof protection. Waterproof breathable fabrics can be produced by nano-scale modification of the surface roughness, thus allowing water and dirt to roll off the surface, but water vapour can still pass from the inside of the clothing through to the surface of the fabrics. Kang et al have produced breathable waterproof fabrics by applying a nano-scaled electrospun polyurethane coating on the fabric surface[54].

(b). Reinforced textiles/Tear and wear resistant textiles

Nanotechnology can be used to change and improve the mechanical properties of textile fibers according to the corresponding application. Such properties include increased tensile strength, elasticity or fiber stiffness[55-57]. These properties can lead to stronger or more elastic textiles or increase the tear and wear resistance of a fabric.

The probably most investigated way of improving the mechanical properties of textiles trough nanoengineering is the integration of CNT which was found to be able to increase tensile strength or elasticity significantly[55,58]. CNT reinforced fibers were produced by melt compounding CNT with polystyrene (PS) and polypropylene (PP) or the production of a CNT-PP Masterbatch, both followed by melt spinning.[58] uses the coflowing of a CNT dispersion during solution spinning to produce reinforced polyvinyl-alcohol (PVA) reports the production of PVA-CNT-composite fibers with increased strength by a modified solution spinning process. CNT can also be applied to the fabric by spray-coating or simply dipping the textile into a CNT solution Apart from CNT, also other NP were reported to alter or improve the mechanical properties of the textile fibers.[58]

(c). Improved colourability / Enhanced bleaching resistance

In connection with the dyeing of textiles, nanoengineering can fulfill the following functions:

- Nanoparticulate pigments can directly be used as dyes.[59]
- Textile surfaces can be treated with nanostructured coatings to render them hydrophilic and improve their colourability[75].
- Dyes can be included into nano-thin coatings to improve bleaching resistance and leaching stability.[57]

The use of nanoparticles as dyes is reported,[59] where cotton, acrylic, and nylon textile are dyed with surface modified. To improve the colourability of textiles surfaces [58] a hydrophilic nano-thin coating trough plasma polymerization of C2H2 mixed with ammonia is produced. The resulting hydrophilic coating and the included functional groups enable substrate independent dyeing. After coating the surface of polyester fabrics, the textile was dyed with acid dyestuffs. Without surface modification, this would be impossible due to the lack of amino groups on the polyester surface which are needed for the dye-fiber reaction mechanism of this group of dyestuffs.[57]

2.2.3 Health Applications

(a). Antibacterial textiles

The antibacterial or antimicrobial properties of textiles can be relised by coating the textiles with nano-sized silver, titanium dioxide and zinc oxide particles. The use of nanotechnology provides increased numbers of particles per unit area, thus maximising the antibacterial effect[60].

The other properties imparted to textiles using nanotechnology are such as wrinkle resistance, anti-static, improvement of dyeability and so on.

(b). Self cleaning" textiles

"Self cleaning" properties in textiles can basically be achieved by three different processes. First is the integration of NP that act as photocatalyst and are able to degrade organic dirt and stains.[67,68] The second method is the production of superhydrophobic surfaces which provide stain and grime repellency and are "self-cleaned" by the rolling water drops that collect dust and other debris [6861] (Section B). Furthermore, antiadhesive surfaces with repellent properties towards specific compounds or substances, as for example proteins, can be designed trough nanoengineering.

2.3 Applications of nanotechnology in functional textile -- Nanofinishing and Nanocoating

In the many applications of nanotechnology, textileindustry has been currently approved as one of the most benefited sector.[62] As discussed above, application of the nanotechnology in textile industry has significantly increased the properties of textiles, such as durability, comfortness, hygienic properties and also cost-reduced. Through improving textiles' properties, a number of advantages of the nanotechnology are realized in terms of economy, energy saving, eco-friendliness, control release of substances, packaging, separating and storing materials on a microscopic scale for later use and release under control. [62]

In this section, we will study what kinds of nanotechnology and nanomaterials can be applied on the textiles to achieve the above improved functions and properties.

Nanofinishing or the finishing using nanotechnology can be various based on the property achieved in the final textile products.[63]

2.3.1 Oil and water repellent nanofinishes

The traditional silicon-based waterproofing in combination with fluorocarbon-based agents cannot match the public demand due to high price and low liability, which Nanotechnology-based novel and innovative nanofinishes can achieve these demands. One example is the Nano Care® and NanoPel® nanofinishes marketed by the US Company, NanoTex Inc. (www.nano-tex.com). Nano Care textiles are created by modifying the outer surfaces of the cylindrical cotton textiles.

2.3.2 Super hydrophobic nanofinishes

In 1990, Wilhelm Barthlott discovered that the lotus has the property of self-cleaning due to the high density of miniature surface protrusions.[64] The ‘Lotus Effect’ results in the super-hydrophobic surfaces and self-cleaning phenomenon. Super-hydrophobic silica-based surfaces have been prepared by the sol–gel process based on silica nanoparticles and perfluoro-octylated quaternary ammonium silica coupling agent (PFSC) using cotton fabrics as a substrate.[65]

2.3.3 Hydrophilic nanofinishes

The poor moisture absorption property of textiles such as polyester and polyamides limits its applications in the apparel sector. The new range of hydrophilic nanofinishes ‘Cotton touch’™ and ‘Coolest Comfort’™, commercialized by NanoTex, USA, makes the synthetic textile look and feel like cotton (www.nano-tex.com).[66] These finishes improve the moisture absorption of polyamides and polyesters, making them hydrophilic and comfortable.

2.3.4 UV protective nanofinishes

The most important function performed by the UV protective textile is to protect the people from the weather and the harmful ultraviolet radiations of the sun. ZnO nanoparticles enhance the UV-blocking property due to its increased surface area and intense absorption in the UV region, and ZnO nanoparticles can also achieve cost-effectiveness, whiteness and UV-blocking property over nano-silver.[67] ZnO nanoparticles can be prepared by the wet chemical method using zinc nitrate and sodium hydroxide as precursors and soluble starch as the stabilizing agent.[68] These nanoparticles with the average size of 40 nm, could be padded on the bleached cotton fabrics using acrylic binder. About 75% UV blocking was recorded for the cotton fabrics treated with very low (2%) concentration of ZnO nanoparticles.[68]

2.3.5 Sol-gel nanocoating

Nanocoating the surface of textiles and clothing is the new approach to the production of highly active surfaces to achieve the properties such as UV-blocking, antimicrobial and self-cleaning properties with exceptional durability and minimum coat weight[67]. Conventional grinding cannot produce small particles (20 to 40 nm in size), but it is easy to produce by sol-gel processing.[69] Low Temperature Sol-gel based nanocoatings have been recently used to deposit layers of metal oxide nanoparticles on textile surfaces for the functionality, such as nanotitania (TiO_2) for photocatalytic.[70]

2.4 Opportunity and Challenge of Nanotechnology in Textile

The EU market size of PPE is estimated to be worth €9.5-10 billion and is forecasted to grow by 7.6% in the period of 2012-2016 because of the rising awareness in personal protection.[19] Similarly, the use of nanotechnology for making textiles is expected to grow rapidly and the highest growth rate is predicted outside of traditional textiles such as protective textiles, which are less sensitive to cost[19].

New threats and challenges of nanotechnology on textile has been raised and discussed both in the workplace and in daily life, which makes important driver for further nanotechnology developments in the protective textiles market. Moreover, strict regulations and growing workplace standards will push protective textile manufacturers forward to explore new technologies. Therefore, strong socio-economic market drivers will strengthen the diffusion process of nanotechnology application in protective textiles manufacturing.

It becomes very important to make sure the development and commercialization of the nanotechnology on textile with full risk control for the public health and enviornment, which we will use risk management system to achieve it. In the next chapter, we will discuss the risk management and the detailed models for the nanotechnology.

Chapter 3

Risk Management for Nanotechnology

Nanotechnology is facing both unprecedented challenges and unparalleled opportunities in a wide regime including research & development, promotion, commercialization, protection and so on.[71] It has become very important to take account the risks and benefits of nanotechnology applications. In this regard, risk management is essential and critical for countering risks associated with both product development and introduction to marketplace. In this thesis, we focus on market risks in the product commercialization process because the unethical behaviours such as illegal imitations and counterfeit products manufacturing may be associated with health problem and environmental safety. In this chapter, we will discuss the risk management principles for Nanotechnology, two models of risk management for nanotechnology and risk management in the target market (China).

3.1 Risk Management Principles for Nanotechnology

During the process of emerging from laboratory into industry, nanotechnology has been facing the risks and problems associated with health, safety and environment as what has been reported by the Royal Society and the Royal Academy of Engineering of the UK.[72] It has been approved that it is the emerging technology novel to take an anticipatory approach to assessing the benefits and regulating risks.[73]. The traditional risk management approach (such as acceptable risk, cost–benefit analysis) and the new risk management approach (precautionary principle) will be applied to reduce the impediment and challenge for nanotechnology in this thesis.

There are a lot of argue about the best risk management for nanotechnology.[71, 74] Here, we would like to see risk management principles for nanotechnology based on two types of perspective:

Top-down perspective: issuing risk management by government; normally, using the traditional risk management models.

Bottom-up perspective: creating science-based techniques to control risk based on uncertainty; other approaches, like precautionary principle, including privacy and civil liberties, intellectual property, and international law.

3.1.1 Traditional Risk Management Principles

There are three most commonly used models for traditional risk management: (a) acceptable risk, (b) cost-benefit analysis, and (c) feasibility (or best available technology).[75, 76]

(a) Acceptable risk approach

Acceptable risk approaches rely on risk assessment and management to describe the risks of an agent – nanotechnology here, and then try to reduce risks to levels that are socially acceptable.[77, 78] However, it is difficult to obtain meaningful risk assessment due to the uncertain understanding of nanotechnology, and it is likely to remain so for a while.[79] Moreover, currently, there are no accepted and fixed-process testing methods which can be applied to prepare scientifically credible quantitative estimations of risk associated with the specific nanotechnology applications.[80, 81] For example, different forms of single-walled nanotubes, like carbon nanotube, present extremely different risks depending on the manufacturing processes and facilities.[88] The toxicity of nanomaterials appears to be determined by a complex set of characteristics, including size, surface area, chemical composition, coating, shape, and route of exposure, i.e. the bulk materials or nanomaterials with different characteristics might not show toxicity.[79, 82]

Acceptable risk approaches can be used to judge the feasibility or infeasibility from a scientific perspective and legal perspective. Generally, the regulators are in the lack of enough information to analyze practical issues and the ways of dealing with these issues.[83]

The timing of risk management approach is also important as it is related to whether the risk assessment can match the rapid pace of nanotechnology development or not.[78] For example, the White Paper issued by the US Environmental Protection Agency shows a timeline for oversight but not until the year 2011 or 2012 that the agency has had sufficient knowledge about the risk and then developed a systematic approach to managing the risks of nanotechnologies.[84]

So, generally, the acceptable risk approaches are restricted and can only help us consider the risks and disadvantages about nanotechnology in this thesis.

(b) Cost–benefit analysis or balancing approach

Cost–benefit analysis or balancing is the second traditional risk management model in analyzing and balancing both costs and benefits. Cost–benefit analysis model is different from the first model -- acceptable risk model, in terms of both the benefits and risks of nanotechnology, for example, it allows nanotechnology to show both risks and benefits for public health and the environment.[83] But, cost–benefit analysis model is ill-equipped at the current stage due to the huge uncertainties

It would make this approach unfeasible for such enormous number and diversity of potential nanotechnology applications if a global cost–benefit balancing for different nanotechnology applications.[71]

(c) Feasibility or best available technology approach.

The feasibility or best available technology approach is the third traditional risk management principle. It requires the reduction of risks in order to achieve the technological or economic feasibility at the lowest level, which has obvious advantage of not requiring information about risks or benefits.

The feasibility approach has achieved considerable popularity recently because it avoids risk analysis and jumps straight to reduce risks to the acceptable extent.[85, 86]

However, the feasibility approach might overregulate or under-regulate the risks of nanotechnology depending on whether or not people can find the best available technology to reduce risks. This can be particularly problematic for an emerging technology such as nanotechnology.

For nanotechnology, it is still not clear how the best available technology approach works as we don’t have enough knowledge to go further and acquire technology controls on production processes, including pollution control of emissions, nature, level, controllability and risks of released nanoparticles.[71]

In sum, none of the above three traditional models of risk management can effectively manage the risks of nanotechnology as there are many uncertainties and risks associated with this emerging technology. Therefore, in the thesis, we use the model of national innovation system (NIS) to assist our analysis of managing traditional risks arising from our product introduction.

3.1.2 Precautionary Risk Management Principle

As the traditional risk management models cannot cover all types of nanotechnology now, many researchers support the usage of precautionary principle for managing the risks associated with nanotechnology, which has become an alternative approach to risk management as "better safe than sorry".[71] The precautionary principle identifies that decisions regarding health and environment must be made in the face of pervasive uncertainty by delaying new technologies until the health and safety can be adequately ensured.[87]

The precautionary approach implies that nanomaterials should be placed in the highest hazard category unless sufficient information is available to justify that lower level of risk management is required.

There are a few problems with the precautionary approach:

- Too poorly defined to serve as a decisionmaking rule, i.e. there is no standard text for the principle and so many formulations suggested differ in important respects.[88]
- Biased toward the status quo, even if the nanotechnology may eventually prove beneficial for the environment or public health.[89]

There are several problems associated with this nano-catastrophism argument but we won't discuss in details here.

Now, it is clear that banning nanotechnology based on the precautionary principle can prevent creating a future catastrophic risk to humankind. How to restrict nanotechnology development in the precautionary principle has become very important. In this thesis, we consider that more and more nanotechnologies have already been or are going to be developed in the lab. It indicates that the risk of misusing or exposure by mistaken is increasing potentially. One of most necessary approaches is to keep intellectual property right (IPR) of nanotechnology safe.

3.2 Two models of risk management for nanotechnology

Managing risk is one of the primary objectives of firms operating internationally. How firms manage risks and how well they manage risks in their business operations can largely affect their firm performance[17]. The technological risks arise when a firm develops new product or enters new production line[14]. The market risks arise when a firm enters market, contacts consumers and commercializes its new product[15]. The market risks are associated with formal and informal institutional context of a country[16].

Institutions are constraints designed by human beings, which structure political, economic and social interactions[18]. Institutions include formal institutions and informal institutions. Formal institutions are rules, regulations, laws, property rights and national innovation system[17]. This project will be focusing on the impact of formal institutions on the commercialization of a new product and the risks associated. Formal institutions constrain the innovation activities of firms. Such formal institutional constrains start from the R&D activities and technological development of new products by firms, to the commercialization of new products, and to the rest of the value chain[17]. In this thesis, we will particularly focus on the two important elements of formal institutions: national innovation system (NIS) and property right protection (IPR in this thesis) and use them as two models of risk management.

Below, we will discuss two models of risk management: National Innovation System (NIS) as one of the traditional risk management principles and Intellectual Property Right as one of the precautionary risk management principle.

3.2.1 National Innovation System (NIS)

The definition of National Innovation System (NIS) is organized by Economic Cooperation and Development (OECD)[90]:

- " .. the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies."[91]
- " .. the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge ... and are either located within or rooted inside the borders of a nation state."[92]
- "... a set of institutions whose interactions determine the innovative performance ... of national firms."[93]
- " .. the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change generating activities) in a country."[94]
- ".. that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and

> implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies.”[95]

The national innovation system (NIS) is a complex and evolving system which is associated with interactions and communication between and inside various social agents such as R&D organizations, universities and governmental institutions, research bureau and so on.[91]

NIS would affect and determine R&D activities, new product development and technological competence via making institutional rules, issuing industrial standards, offering research resources, providing guidance and information, and so on. NIS also affects the level of information and knowledge sharing, technology-based and experience-based learning which shows that NIS is very important and useful for both national level and firm level.[90]

There are a number of benefits to have a strong NIS which is associated with strong interactions and communication between organizations to enhance knowledge and experience sharing:[96]

- to offer resources, supports, R&D infrastructures, technological information and services to firms in order to assist their R&D and form the knowledge base.[96]
- to reduce the risks associated with both new product development and commercialization;[100]
- to obtain the resources, governmental supports, R&D infrastructures and technological information and services;[97]
- to help firms better deal with risks and minimize the harms generated by risks.[93]

So, NIS is playing an important role in assisting firms with risk management.

Here, it is worth mentioning one part of NIS -- formal institutional supports, which can help firms protect returns from R&D activities with well-established law system such as IPR system[97]. Also, strong formal institutions can help firms acquire technological information and services via building networks and facilitating interactions between firms. The learning, knowledge and technological knowhow can also be enhanced and shared with strong formal institutions.[88] With strong formal institutional supports and services such as high-quality information regarding the market and industry status, adequate channels to financing and low tax burden, firms are able to adopt various strategies effectively and efficiently to counter commercial risks, and build channels to disperse uncertainties.[89]

3.2.2 Intellectual Property Right (IPR)

It is important to keep the IP of nanotechnology can be used only by IP authorized people or organizations who have full range of risk management for nanotechnology. Otherwise, it may easily cause the health and environmental problems and risks due to plagiarizing IP by those who do not have full knowledge of risk management.

Intellectual Property Right (IPR) is set up for granting temporary and exclusive rights[98]. This is normally done using forms such as patenting. Since knowledge has an intangible and public good nature, the temporarily exclusive rights can protect the interests and returns of innovation[98] and also the correct usage methods. As an important part of formal institutions, IPR aims to protect inventors from being copied and provide incentives for doing R&D. In return, the inventor has to publish information on invention after a period of time when the patent expires.[99]

An effective and functional IPR system and the required disclosure of information mechanism through patenting are socially useful in at least two ways.

First, it restricts the amount of imitation activities when the new product comes out and protects the interests of innovators by providing incentives to them and guaranteeing their returns[100]. The benefits such as reputation from innovation, financial returns and exclusive right in sales can be guaranteed, starting from the patent is granted, until the patent is expired.[100] In this regard, part of market risks associated with commercialization of new products can be managed to a certain extent because the returns to innovators are guaranteed and protected.

Second, the afterwards information disclosure mechanism enables other firms to make use of the technological information, knowledge and spillovers from innovators.[101] Such process can facilitate learning, knowledge sharing and interactions between firms. The knowledge base and accumulated experience in R&D can be formed then.[101]

In this regard, part of technological risks associated with development of new products can be managed to some degree, because these later comers do not have to totally rely on their own R&D but take advantage of technological spillovers from first movers.[101] Therefore, with a strong and effective IPR system, it is mutually beneficial for both pioneers and later comers in terms of technological performance and rate of innovation. It is also vital to make sure all players have full knowledge of using the technology and materials, like nanotechnology and nanomaterials.

3.3 Risk Management in aim market (China)

As China is the top textile play either on manufacture and exporting, it becomes very important to consider the current and future situation of nanotechnology for textile. These 2 models applied the nanotechnology in China are also discussed below.

3.3.1 The importance of the aim market: China

As one of the fastest-growing emerging countries, China has gone through tremendous development in economy, political system, institutions and technology.[102] Chinese people's living standard and purchasing power have been increasing during the past twenty years. Many foreign firms and foreign investors are keeping attracted by China.[103].

There is general proof that consumers are prepared to pay extra for the key consideration of easy care.[103] As a result fabric with nanofinish has allowed companies to significantly distinguish their apparel lines and tap into the expansion opportunities formed by growing consumer demand for convenience and easy care. The textiles market is also being advanced by changes in consumer lifestyles as people are living longer and spending more time on leisure activities.

China is making great efforts to encourage R&D and innovation such as building large R&D centers in China.[102] In order to encourage both indigenous and foreign R&D and innovation and building links between them, Chinese government has been not only offering financial supports but also reducing tax upon foreign assets, in order to improve intellectual property right protection system and eliminating illegal imitations[103]. During this process, Chinese national innovation system and intellectual property right system are playing a key role in providing incentives and returns to investors of R&D. Therefore, in this regard, China is a very important target country for us to investigate technological risks and management risks associated with product development and commercialization in a new institutional context rather than UK.

3.3.2 NIS in China

China is making great efforts in R&D and development of its NIS. It is suggested that China aims to become an innovative nation by 2020 and a world leader in science and technology by 2050[104]. In order to reach this objective, the Ministry of Science and Technology of China (MOST) has made corresponding plans which stress various means to facilitate indigenous R&D and innovation. Among these plans, the Science and Technology Development Plan (STDP) is of great importance[105]. It addresses four main policies including tax policies, procurement laws, IPR laws and national technology standards[102].

NIS in China aims to offer more supports to domestic R&D pioneers and foreign R&D investors. It also tries to encourage innovation over imitation.[106] In China’s NIS, the government is playing a significant role in at least four areas. First, it guides the resource allocation to firms’ R&D. Second, it manages the networking and interactions between various organizations in NIS. Third, it intervenes firms’ R&D. Last, it monitors and assesses the functioning of NIS.

China has made various efforts to develop NIS:

- Chinese government is playing an important role in building NIS. Since its reform and opening up, China has made lots of efforts in building up its Science and Technology System which aims to facilitate indigenous R&D.

- The setting up and enforcement of key national science and technology programs has facilitated the interactions, communication and cooperation between firms, scientific research institutions and universities. As a result, the information sharing, experience accumulation and knowledge acquisition are promoted.[106]
- NIS in China still has some features developed under the previous planed economic system which may hinder the R&D of firms such as government interventions[102]. Therefore, it is essential for China to improve its NIS system and strengthen role of enterprises and market in leading R&D.
- The intermediary organizations and technological information and services are underdeveloped.[99]

Despite the great efforts and progress made by Chinese government on NIS, the further reform and improvements on NIS is still required.[107] NIS in China is still weak in many areas which hinder firms' R&D and innovation. For example, the access to high-quality information regarding technology and market is sometimes hard to obtain. Also, the difficulty in accessing to finance further blocks innovation of firms. The stories of success and experience by other firms cannot be well shared[104]. The possible government nonfeasance or even corruptions may further hinder the resource allocation and enforcement of government policies on R&D of firms in practice[102]. All of the above negative facts plus the supportive policies in China require carefully planning before entering Chinese market.

3.3.3 IPR in China

The protection of IPR is one of the main concerns in the commercialization of new products, particularly in China. China has made a lot of improvements in the enforcement and implementation of IPR regulations and laws. Since China opened its door in 1979, the Chinese government has realized the importance of protecting IPR[107]. Since 1994, China is a member of Patent Cooperation Treaty (PCT), and since 2001, China has actively taken part in several agreements on international and national IRP protection. The most important ones are Trade Related of Intellectual Property Rights (TRIPS) and National Intellectual Property Strategy (NIPS)[108].

As China has obligations to enforce and improve IPR protection under the WTO Agreement on TRIPS and its WTO Accession Protocol, it requires China to take further actions on IPR protection. The enforcement of TRIPS is one of the core obligations of China's joining WTO.[109] TRIPS covers the protections of trademarks, patents, copyrights, industrial designs, trade secrets, geographical indicators and integrated circuit industrial designs. TRIPS stresses various IPR laws upon China and it provides the systematic resolution of disputes according to the Dispute Settlement Understanding (DSU) provisions.[107] The agreement aims to provide China with security, predictability and establish IPR protection as an integral part of the WTO multilateral trade system. TRIPS contributes significantly in terms of assisting China with the advancement of its own IPR system and building up its NIS. On the other hand, however, China needs to make further improvements and take more actions as China's IPR framework currently only meets the minimum requirements of TRIPS and it lacks adequate enforcement/punishment on illegal activities associated with IPR.[107]

National Intellectual Property Strategy (NIPS) is also playing a significant role in China's IRP system. NIPS aims to promote China's efforts on IPR.[110] NIPS makes the government to "guide and support Chinese market entities to create and utilize intellectual property" through policies linked to indigenous R&D.[110] NIPS has several targets including significantly increasing the quality and quantity of China's indigenous IP, developing a group of internationally famous brands, increasing values in core copyright industries and effectively protecting trade secrets. China's Supreme People's Court is the key governmental institution which monitor, enforces and stimulate NIPS[103].

Meanwhile, China's IPR is still threatened by illegal imitations. For example, it suggests that China's food and drink product markets are flooded with counterfeits and 'me-too' products.[106] Many small firms in China illegally and duplicately imitate the original products, put on the same brand logos or slightly different brand logos which look very similar to the original logos. In the long run, these products not only undermine the sustainability and long-term success of firms which produce illegal imitations, but also threat the profitability and reputation of the original producers of these products[103]. Therefore, it requires efforts and effective punishment mechanism of Chinese government to reduce the illegal imitations and encourage original innovation. It requires not only a stronger IPR law system, but also stronger power of enforcement by Chinese government of all levels.

Chapter 4 Magnetic Nanoparticles for Functional Textile

4.1 Magnetic Nanoparticles used on Functional Textile

To achieve the proposed functionalized textiles, several types of magnetic nanoparticles are selected from a range of well described magnetic nanoparticles. These magnetic nanoparticles are applied to the textiles by coating and finishing techniques. Detailed descriptions of related theoretical knowledge, design concepts, fabrication and measurement techniques are introduced. The ultimate aim of the experiments for the particular magnetic nanoparticles is to develop useful functions for the textile which have commercialization opportunities.

The experiments can thus be divided into two main stages: (1). fabrication, i.e. coating magnetic nanoparticles on the textile samples; (2). characteristics of samples. Based on the experimental results, the analysis will be discussed.

4.1.1 Types of Magnetic Nanoparticles

There is a wide range of magnetic nanoparticles, including: nanoparticles of magnetic metals, simple and complex magnetic oxides, and alloys.

(a). Metal

The metallic nanoparticles have larger magnetization compared to other types of magnetic nanoparticles like metal oxides.[111,112] It has been interesting for many applications for a long time, but metallic magnetic nanoparticles are not air stable, i.e. easily oxidized.[113] The main types of metallic magnetic nanoparticles are:

Fe: for the particle size varied in the range of 10–20 nm;[114] 10nm Fe powder;[115]

Co: nanocrystals with a specific size and even shape;[116, 117]

Ni: nanoparticles used for thermal decomposition,[118] sol–gel;[119]

(b). Nanoparticles of Rare Earth Metals

As six of the nine rare earth elements (REE) are ferromagnetic, the magnetic nanomaterials based on these REE has a special role, such as using in magnetic cooling systems.[120] However, REE nanoparticles have been widely applied due to the high chemical activity of highly dispersed REE.[121]

Some types of REE are studied by researchers: Gd, Dy, and Tb nanoparticles with an average size of 1.5–2.1 nm;[122] coercive forces diminishing on Tb and Gd nanoparticles when size reduced from ∼10 nm to <10 nm.[123]

(c). Magnetic Alloys

Fe–Co Alloys: It is well known that Co and Fe form a body-centered-cubic (*bcc*) solid solution over an extensive range.[124] The Fe-Co nanoparticles (40–51 nm) can be prepared in a stream of hydrogen plasma.[125]

Fe-Ni: The Fe–Ni nanoparticles have a much lower saturation magnetization than the corresponding bulk samples,[126] especially when the nanoparticles down to 12-80nm showing superparamagnetic over a broad temperature range.[127,128]

Fe–Pt: The face-centered tetragonal (*fct*) (also known as L10 phase) FePt alloy possesses a very high uniaxial magnetocrystalline anisotropy which is more than 10 times as high as that of the currently utilized CoCr-based alloys.[129] The FePt nanoparticles with a narrow size distribution were achieved by joint thermolysis of $Fe(CO)_5$ and $Pt(acac)_2$, with the size around 6nm.[130, 131]

Co–Pt: CoPt nanoparticles has the impressive magnetic properties according to their size, form, and crystal structure render them as important materials for high density information storage.[132] CoPt nanoparticles can be obtained with a narrow size distribution in the 3–18 nm range.[133]

(d). Magnetic Oxides

Iron Oxides: Iron oxides have received increasing attention due to their extensive applications, such as magnetic recording media, catalysts, pigments, gas sensors and electromagnetic devices[134] and a wide variety of structures and states.[135] Iron oxide particles with size around 30nm show very interesting functions like superparamagnetic, hydrodynamic.[136,137]

Fe_2O_3: The most popular route to Fe_2O_3 nanoparticles used thermal decomposition in various media.[138]

Fe_3O_4 (Magnetite): to be discussed in section 4.1.3.

Ferrites: Microcrystalline and nanocrystalline ferrites are used for magnetic information recording and storage. Nanocrystalline ferrites prepared by different methods are barium ferrite nanoparticles (~50nm),[139, 140] $MnFe_2O_4$ (6-18nm),[141] $SrFe_{12}O_{19}$ nanoparticles (30–80 nm),[142] There are a few other types of magnetic oxides nanoparticles receiving increasing interest, like FeO (Wustite),[143] FeOOH,[144] α-FeOOH (Goethite),[145] Co oxides, Co_3O_4,[146] NiO,[147], etc.

Considering the advantages of various magnetic nanoparticles and the requirement of the risk assessment for using the magnetic nanoparticle in the labs of the University of York, three types of magnetic nanoparticle have been chosen for the experiments: Carbonyl Iron Powder (CIP), Fe_3O_4 and Ferrifluids.

4.1.2 Carbonyl Iron Powder (CIP)

Carbonyl iron is a highly pure (97.5% for grade S, 99.5+% for grade R) iron, prepared by chemical decomposition of purified iron pentacarbonyl and invested by BASF in 1925. [148] In 1934, BASF was involved in the development of the very first magnetic tapes used by the AEG Magnetophon tape recorder so that carbonyl iron became the first magnetic recording oxide (although quickly replaced in 1936 by iron oxide).[149]

Carbonyl iron is also used to manufacture magnetic cores for high-frequency coils with high stability of parameters across a wide range of temperatures and magnetic flux levels.

Fig. 8 Carbonyl Iron Particle invested by BASF more than 80 years.[148]

It usually has the appearance of grey powder as seen in the above figure, composed of spherical microparticles, as seen in the below Scanning Electron Microscopy (SEM) image. Most of the impurities are carbon, oxygen, and nitrogen. The particle size is less than 10 micrometers.

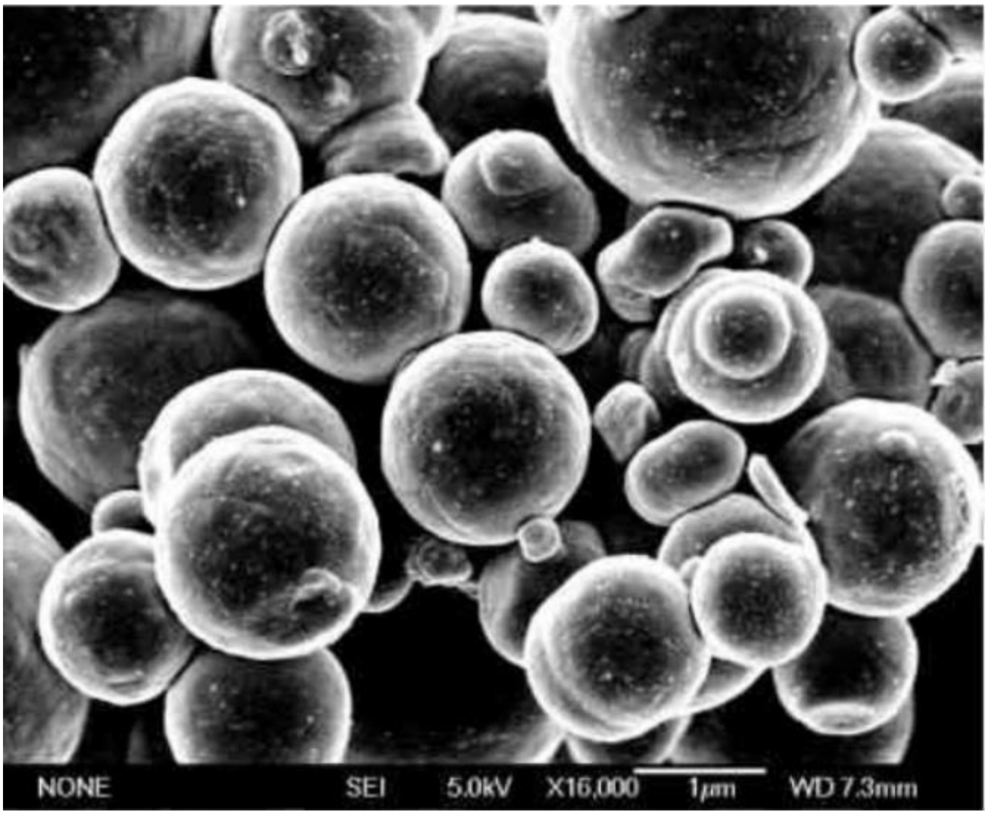


Fig. 9 SEM image of CIP particles.[150]

BASF has announced the Carbonyle iron powder has the property of microwave absorption in their product brochure.[148]

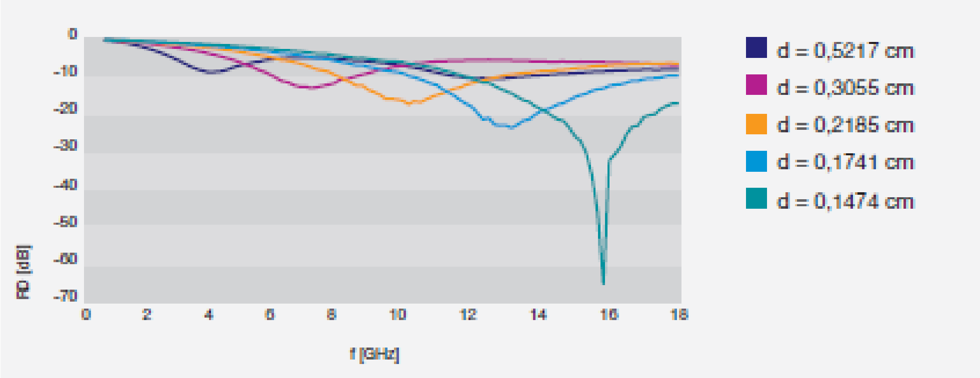

CIP ER in melamine matrix (30 Vol. %)

Fig. 10 The absorbing status of CIP in different consentration of melamine matrix. [148]

In the above figure, it shows that CIP can efficiently absorption RF from 1GHz to 18GHz. For this reason this commercial material was chosen for the experiments.

4.1.3 Magnetite (Fe_3O_4)

Among all types of iron oxides, magnetite Fe_3O_4 has the most interesting properties due to the presence of iron cations in two valence states, Fe^{2+} and Fe^{3+}, in the inverse spinel structure.[151] The cubic spinel Fe_3O_4 is ferrimagnetic at temperatures below 858 K.[152] The Fe_3O_4 nanoparticles can be created using $FeCl_2$ and oxidant ($NaNO_2$) to allows the particle size varied from 6.5nm to 38nm and the particle shape.[153] Another method to create the very fine Fe_3O_4 nanoparticles (about 1 nm) is using thermal decomposition of compounds containing Fe^{3+} ions under oxygen-deficient.[154] A number of fabrication methods are also studied to achieve various size of Fe_3O_4 nanoparticles, like 9nm,[155] ~13nm,[156] 8 and 11nm.[157] Fe_3O_4 nanoparticles have very god stabilization in the water media.[158]

In contrast, the Fe_3O_4 nanoparticles with larger size (20m – 100nm) has also raise great interest, mainly for hyperthermia because of their ferrimagnetic behavior at room,[159] which will be carried in the experiments mentioned below.Non hydrolytic sol-gel chemistry has proved to be a promising route to Fe_3O_4.

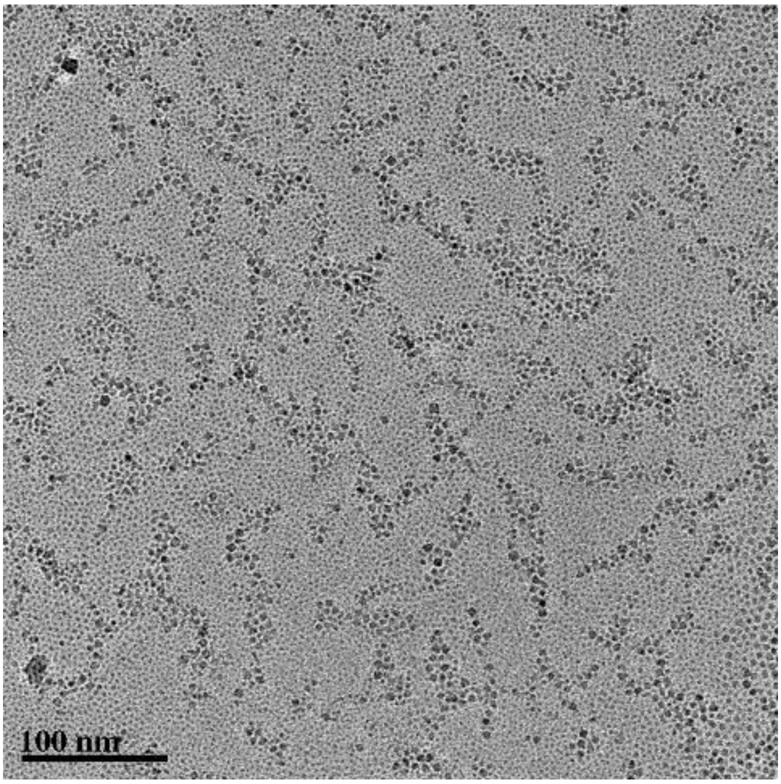


Fig. 11 TEM image of 4 nm Fe_3O_4 nanoparticles prepared from the thermal decomposition of $Fe(acac)_3$.[160]

In superparamagnetic nanoparticles three different limitations have to be considered which are implicated during heating process Neel relaxation, Brownian motion relaxation and hysteresis losses.[161] Moreover, specific loss power has to be optimized for nanoparticles to respond to the alternating magnetic field. Therefore, effective relaxation time has to match the applied alternating magnetic field. Effective relation time is influenced by both Neel relaxation and Brownian motion relaxation.[162]

Fig. 12 Suspension of 20nm diameter Fe_3O_4 particles used in the experiments

Neel relaxation depends on the product of magnetic anisotropy constant and the magnetic core volume. The core volume of the liquid used will remain constant, although the hydrodynamic volume of the solution can be change. However, the slightest discrepancy in size of NPs can affect the relaxation time, it is an exponential dependence.[163]

Brownian relaxation is defined by the fluid viscosity and the hydrodynamic particle volume. It is difficult to control Brownian relaxation due to the dynamic nature of in vivo environment.[164]

Specific power loss will be heavily affected if the hydrodynamic volume will increase. So the conclusion is that the particle size has to be controlled and to do that highly precise sorting process has to be established.[165]

4.1.4 Ferrofluids

Ferrofluids, the colloidal dispersions of magnetic iron oxides in hydrocarbon oil, represent probably the first application of magnetic materials in the new form.[166]

Fig. 13 Ferrofluid spikes by Andrew Magill from Boulder, USA.[167]

Ferrofluids are also called as called magnetic fluids, magnetic nanofluids, superparamagnetic colloid, made from colloidal suspensions of surfactant-coated magnetic nanoparticles in a liquid medium.[168] Now, a wide range of magnetic nanoparticles (including Fe, Co, Ni, FePt, CoPt, various ferrites nanoparticles) has been synthesized as superparamagnetic with narrow size distribution.[169, 170] The possibility of magnetic control of flow and properties of ferrofluids have led to the development to achieve a wide range of possible applications from mechanical engineering to biomedical treatment.[171, 172]

Fig. 14 Suspension of Ferrofluids used in the experiments

The stability of ferrofluids is the one of most important factors, i.e. nanoparticles remain small and shouldn't agglomerate.[173] It could become difficult to balance van der Waals forces between particles and dipolar interactions. The method is to coat the nanoparticles with a polymer (surfactant) layer to isolate one from the other.[173]

When no magnetic field is applied to ferrofluids it is closely modeled as a Newtonian fluid or similar to that of the chosen carrier fluid. When a magnetic field is applied the ferrofluids viscosity will change but only slightly the main benefit of ferrofluids is their ability to be manipulated into different positions.

A typical ferrofluid may contain by volume 5% magnetic solid, 10% surfactant and 85% carrier. The magnetic solid is magnetic nanoparticles which could be cobalt, nickel or iron oxide to name a few but could in theory be any material which exhibits ferromagnetic behavior. The carrier fluid can be used with very little limitation on what can be used. The most common carrier fluids are water, hydrocarbon oils and silicon oils.

4.2 Experimental techniques and sample preparation

The first stage is to fabricate nanoparticle coated textile samples. The fabrication of nanoparticle coated textiles was based on the fabricated nanoparticles and the textiles provided by myself. The coating process was creative and simple utilizing facilities provided in spintronics laboratory under supervision of laboratory supervisors.

The second stage is to examine the protective effectiveness and performance of Radar absorbing materials. In this part, I have visited and collaborated with a lab in Nanjing University, China and used their equipment to examine my samples.

4.2.1 Arch Test for Radar Absorbing Materials

The NRL Arch is a system for testing the absorbing efficiency of flat materials over broad frequency ranges. The NRL Arch is well established and can do the measurement which generates direct retection of the absorbing abilities of samples.

This machine is originated from Naval Research Laboratory (NRL) in the USA in 1945. The purpose at that time was for measuring the performance of Radar Absorbing Materials in a broadband environment. The system from NRL was devised into an arch with one transmitter and one receive antenna.

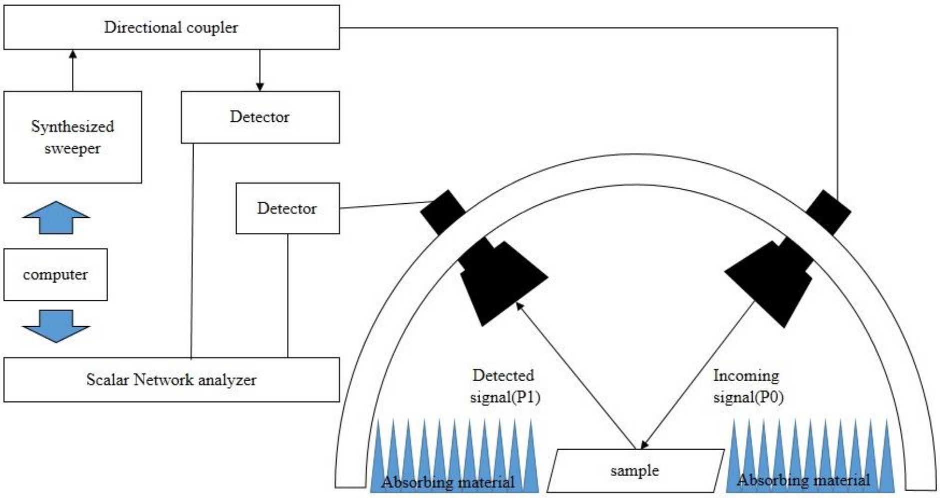


Fig. 15 **The NRL arch system (simplified block diagram of the arch method)**

The antenna and receiver angle can be changed on the angle of the arch, while there is a constant distance between the antennas and samples which are put on a metal plate below the antennas, as shown by figure 15. The metal plate is reflective. The distance between the antennas and the sample is about 30 inches to 36 inches. P1 is the receive point and P0 is the point that generates wave. More information can be found in the reference[174]

4.2.2 Electromagnetic (EM) Wave Shielding Effectiveness (WSE) Measurement

The WSE measurement measures the shielding effectiveness for the shielding of electronic circuits. There are two purposes of shielding. One is to prevent the electronics' emissions generated by the product from radiating outside the border of the product. Another is to stop the emissions generated from outside from obstructing the electronics inside.

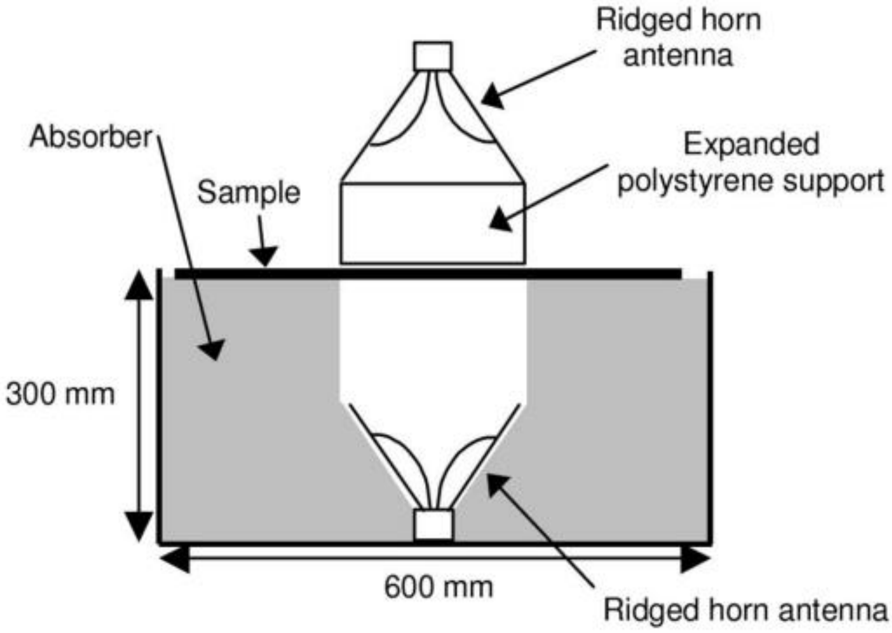


Fig. 16 Absorber system of EM wave shielding effectiveness[175]

We can regard the effectiveness of a shield as being the ratio of magnitude of electric (magnetic) field that is incident on the barrier to the magnitude of the electric (magnetic) field that is transmitted through the barrier. Alternatively, we may view this as the ratio of electric (magnetic) field incident on the product's electronics with the shield removed to that with the shield in place. We can use this measurement to define whether the samples with CIP are capable of RF absorption. More information can be found in the reference[175].

4.2.3 Magnetic Induction Hyperthermia (MIH) Measurement

Hyperthermia is now being used for treatment of cancers in the brain, especially that of infants. Previously, it was used as a treatment for body issue which was exposed to high temperatures in order to destroy harmful items such as cancer cells, called hyperthermia. Hyperthermia has the particular advantage of focused heating on cancer cells without damaging other surrounding body tissues.

The features of Hyperthermia can also be applied to other fields such as making some items hot in a short time. In the experiment, the nanoparticles will be measured and we want to investigate the extent of difference between three particle types.

An induction coil, which is useful for hyperthermia treatments, will be appropriate equipment for heating.

In an inductive coil, a current is induced on a material which generates heat when the magnetic field in the induction coil changes near the material if it is an electrical conductor, or a magnetic particle. The heat generated is proportional to the current squared multiplied by the resistance of the material. More information can be found in the reference[176].

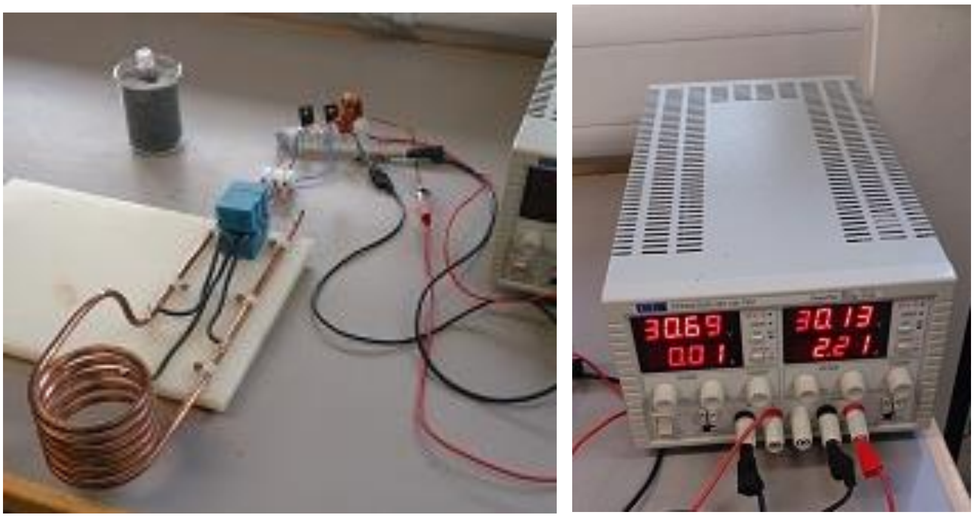


Fig. 17 Inductive coil system used in the experiments.

Here, L1 is the heating coil and also the place which holds the beaker with the sample inside. The R1 and R2 resistors are 240 ohms, 0.6W and determine how quickly the MOSFETS will turn on. The diodes D1 and D2 are used to discharge the MOSFET gates. D1 and D2 are diodes with a low forward voltage drop. This is the prerequisite of that the gate can be well discharged. The MOSFET is fully off when the other is on. Schottky diodes 1N5819 are used as they have low voltage drop and high speed.

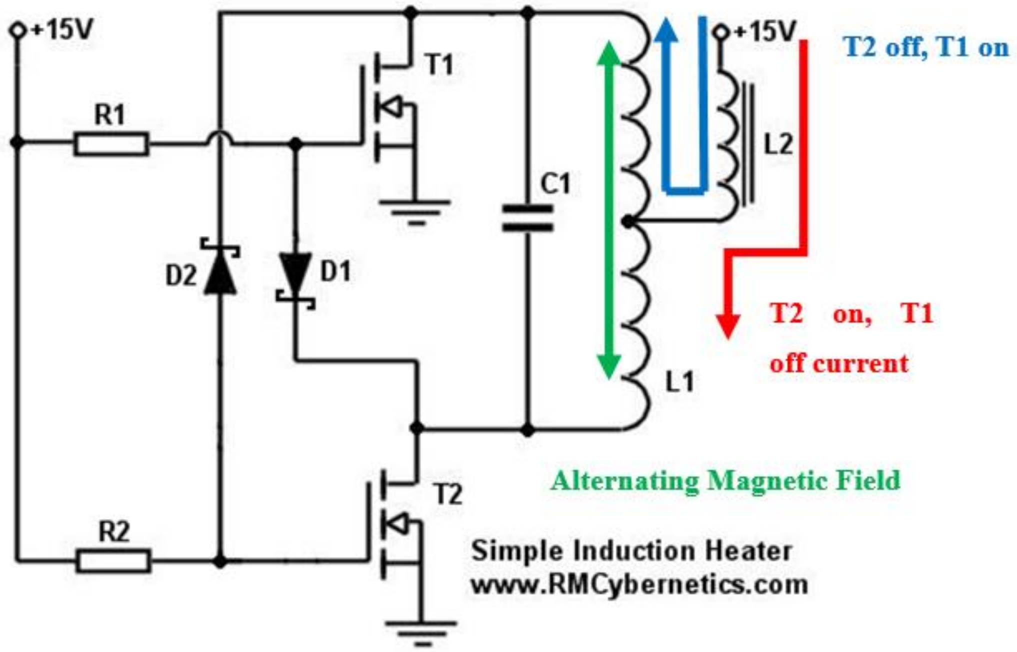


Fig. 18 Circuit diagram of the induction heater

T1 and T2 transistors are 100V 35A MOSFETs(STP30NF10)with low drain-source resistance and quick response time. They should be mounted on heatsinks in order to prevent them from warming up. They switch on and off alternatively(oscillate), for example, T1 is on, T2 is off. Then, T2 is off and T1 is on.

The inductor L2 is an obstacle in order to keep the high frequency oscillations out of the power supply, and to limit current to acceptable levels. The polypropylene capacitors C1 of value 330nF and inductor L1 form the resonant tank circuit of the induction heater they can induce large current and temperatures. See Figures 12 and 13, for the inductive coil built at the Electronics Department of University of York. The frequency of the inductive coil is 87.5kHz.

4.2.4 Sample Preparation

In order to compare the properties of different magnetic nanoparticles, the sample preparation process for different samples was kept similar. In the below experiments, six types of textiles are chosen in the first instance in order to find out the textile with the most suitable property for the tested function.

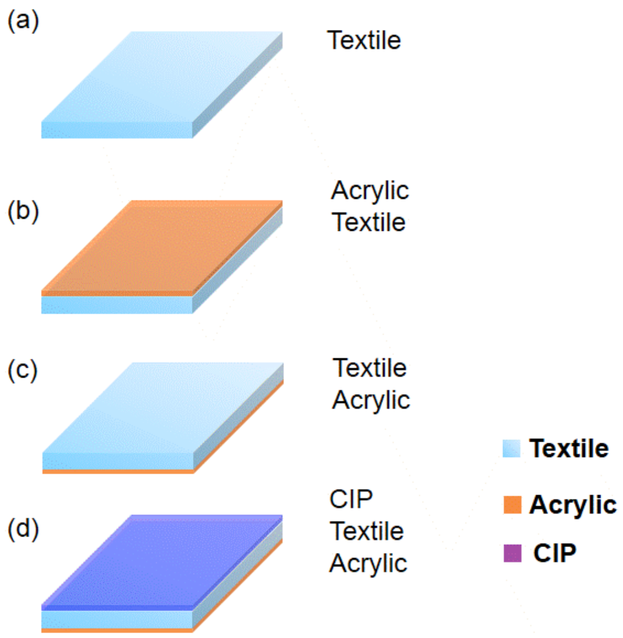
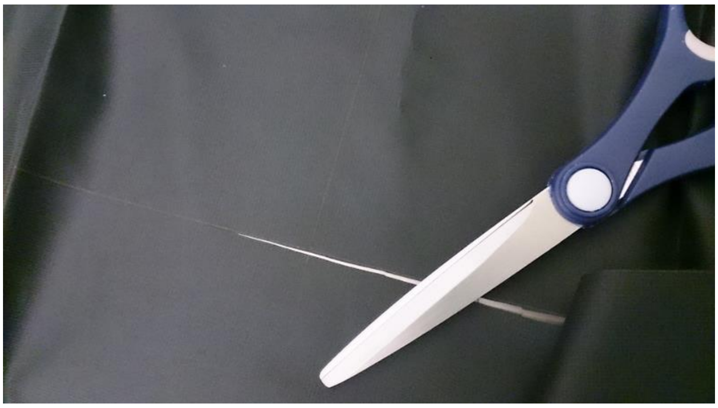
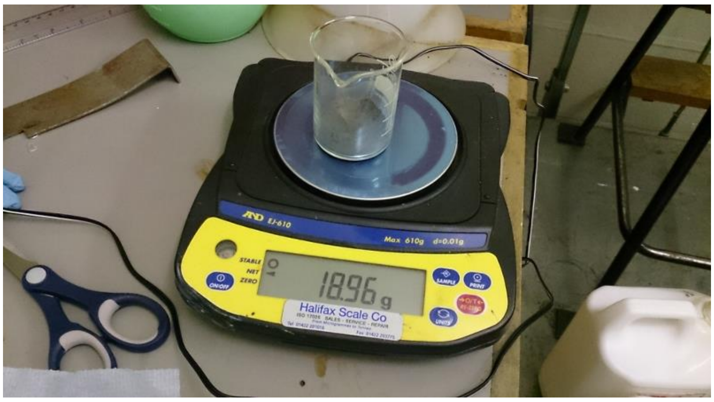


Fig. 19 The diagram of sample preparation processes for carbonyl Fe particles (CIP) applied on the textile: (a) a sheet of textile is cut for the size; (b) a layer of acrylic is applied on one side of textile, (c) layer of CIP suspension are applied on other side of the textile, (d) the dry textile is ready for experiments.

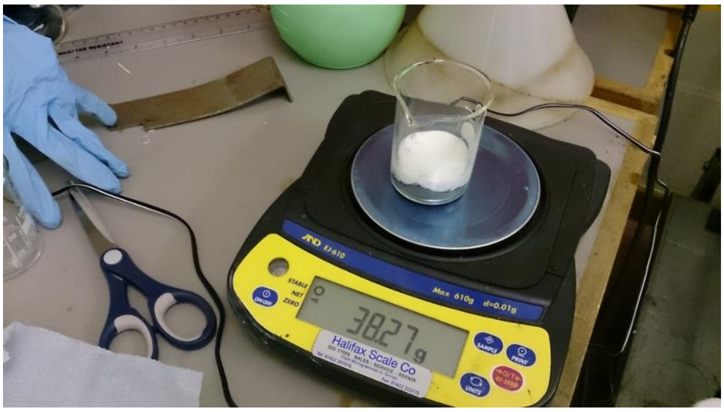
A sheet of textiles with fixed size (20cm x 20 cm, or 2cm x 2 cm depending on the experiment type) is obtained. Then, a layer of acrylic is applied on one side of textiles and a layer of carbonyl Fe particles (CIP) suspension is applied on other side of the textiles. When the textile is dry, the samples are ready for the experiments.



(a)


EJ-610
Max 610g d=0.01g
18.96 g
Halifax Scale Co

(b)


EJ-610
Max 610g d=0.01g
38.27 g
Halifax Scale Co

(c)


142

(d)

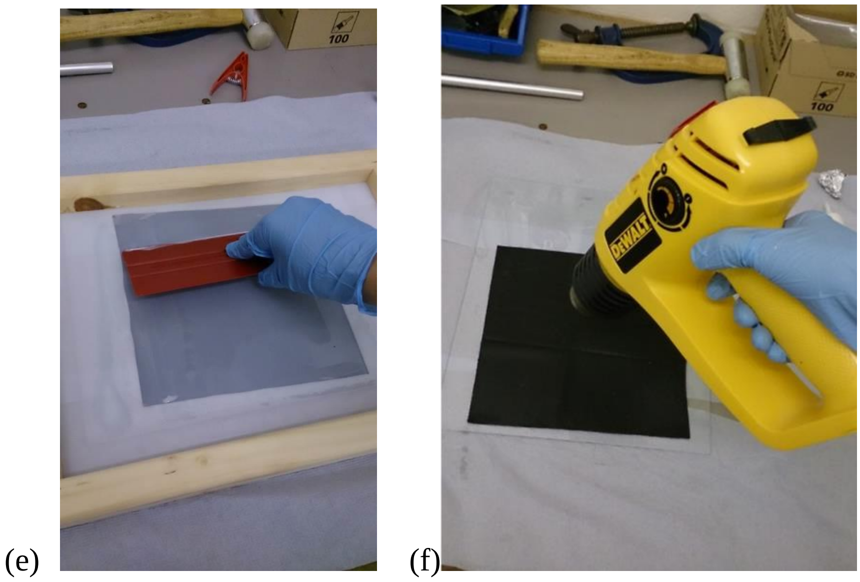


Fig. 20 Sample Preparation processes. (a) Obtain the polyester into appropriate size, (b) weighing nanoparticles in a beaker (CIP), (c) weighing acrylic and mix it with CIP, (d) mixing them and put the beaker in an ultrasonic bath, (e) brush it on the textile, (f) making it dry.

The process of making samples is shown in the above figure including several pictures shown to illustrate the process of making samples using carbonyl iron and acrylic. In detail, the two materials: acrylic and carbonyl with the ratio 1:1(14.5g carbonyl iron and 14.5g acrylic), were brushed onto the fabric (12 samples). Those 12 samples were divided into two groups: textile polyester and polyamides, each group will have six samples with six different concentrates layers from 1 to 6.

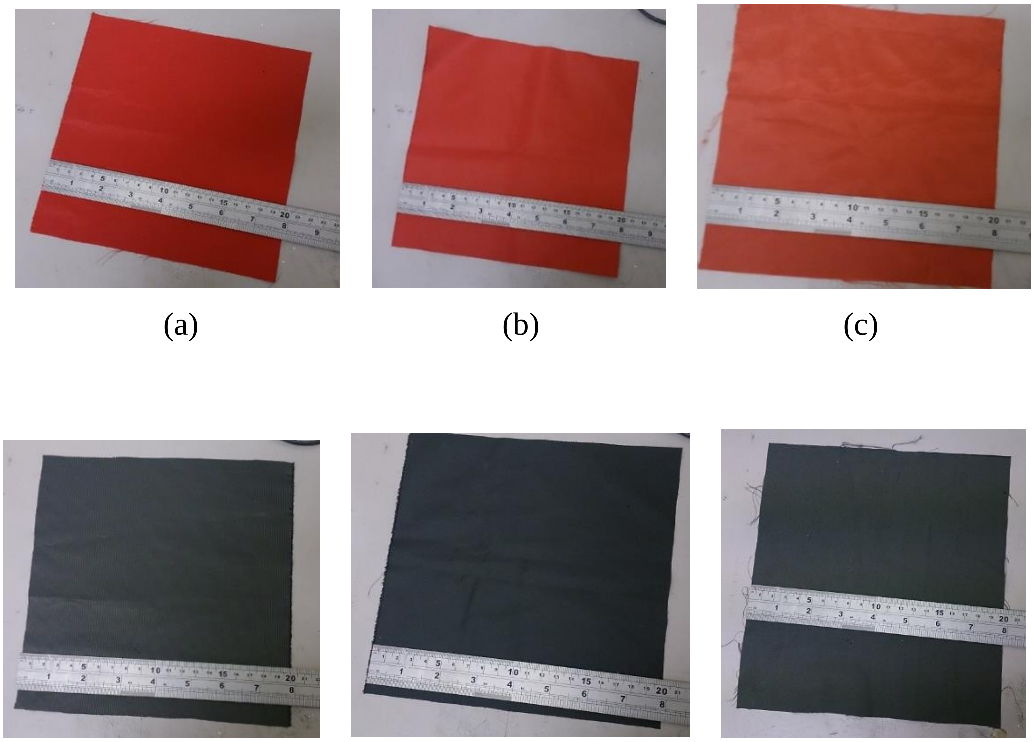
4.3 Results and Analysis

4.3.1 Result of Arch Test

These results illustrate the effect of using six different fabric substrates in order to determine which are most effective at holding a coherent layer of CIP and acrylic coatings. Each fabric and coating was characterized to determine its ability to absorb electromagnetic energy for coatings with varying concentrations of CIP.

The best fabric was selected on the basis of the results and was ultimately coated in a layer containing carbon nanotubes (CNTs) to further improve its performance.

Three different groups of samples are prepared for the measurement of Arch Test for Radar Absorbing materials.


(a) (b) (c)

(d) (e) (f)

Fig. 21 Sample selection process group A: (a). Polyester Red; (b). Polyester 320T; (c). Polyester 50D; (d). Polyamide Korea; (e). Polyamide Pineapple; (f). Polyamide Swiss;

These six kinds of textile are selected as they are those most often used in textile industries. Those textiles which were used in the following experiments are easily obtainable textiles and are polyester and polyamide. Both polyester and polyamide have high densities, flexibility and anti-wear characteristics and are suitable to make coats.

Table 1 Group A sample lists

	Polyester red	Polyester 320T	Polyester 50D	Polyamide Korea	Polyamide Pineapple	Polyamide Swiss
Acrylic only	#01	#02	#03	#04	#05	#06
CIP: Acrylic (1:1)	#07	#08	#09	#10	#11	#12
CIP: Acrylic (1:1.5)	#13	#14	#15	#16	#17	#18
CIP: Acrylic (1:2)	#19	#20	#21	#22	#23	#24

(a). Sample list and results for Group A

Group A: 24 textile samples from 6 different types of textile applied with 4 different types of solution. The 6 different types of textile are polyester red, polyester 320T, polyester 50D, Polyamide Korea, Polyamide Pineapple, Polyamide Swiss. The 4 different types of solution are Acrylic only, solution of carbonyl Fe particles (CIP): Acrylic (1:1), solution of CIP: Acrylic (1:1.5), solution of CIP: Acrylic (1:2).

Table 2 Sample #01~#06 with Acrylic layer only

Sample #	Textile	Original weight	Sample Weight
#01	Polyester red	4.72g	5.89g
#02	Polyester 320T	4.10g	4.69g
#03	Polyester 50D	2.65g	3.49g
#04	Polyamide Korea	5.12g	6.15g
#05	Polyamide Pine	4.13g	5.02g
#06	Polyamide Swiss	5.42g	7.24g

Table 3 Sample #07~#12 with CIP: Acrylic (1:1) = 18.97g : 18.97g

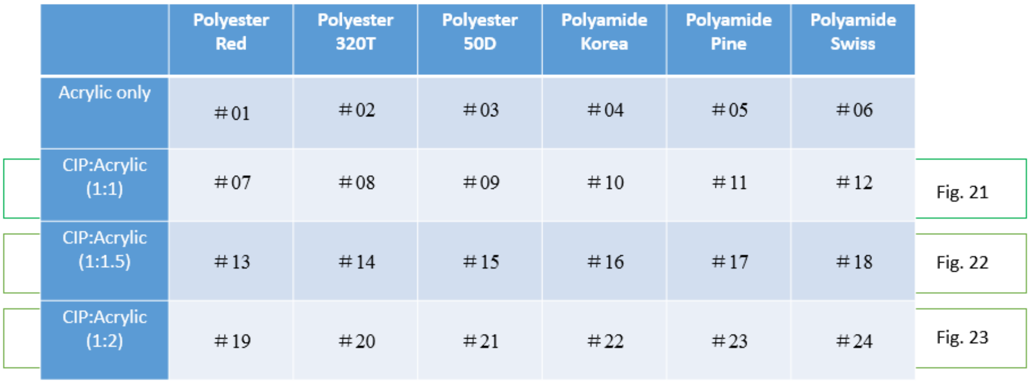
Sample #	Textile	Original weight	Sample Weight
#07	Polyester red	4.71g	7.53g
#08	Polyester 320T	4.17g	7.14g
#09	Polyester 50D	2.70g	4.68g
#10	Polyamide Korea	5.20g	7.32g
#11	Polyamide Pine	4.18g	6.97g
#12	Polyamide Swiss	5.38g	10.39g

Table 4 Sample #13~#18 with CIP: Acrylic (1:1.5) = 20.28g : 30.45g

Sample #	Textile	Original weight	Sample Weight
#13	Polyester red	4.79g	6.24g
#14	Polyester 320T	4.07g	5.34g
#15	Polyester 50D	2.70g	4.36g
#16	Polyamide Korea	5.18g	6.97g
#17	Polyamide Pine	4.23g	6.56g
#18	Polyamide Swiss	5.43g	8.65g

Table 5 Sample #19~#24 with CIP: Acrylic (1:2) = 17.6g : 35.44g

Sample #	Textile	Original weight	Sample Weight
#19	Polyester red	4.75g	6.83g
#20	Polyester 320T	4.16g	5.88g
#21	Polyester 50D	2.78g	4.23g
#22	Polyamide Korea	5.19g	6.79g
#23	Polyamide Pine	4.10g	6.01g
#24	Polyamide Swiss	5.44g	9.31g



	Polyester Red	Polyester 320T	Polyester 50D	Polyamide Korea	Polyamide Pine	Polyamide Swiss	
Acrylic only	#01	#02	#03	#04	#05	#06	
CIP:Acrylic (1:1)	#07	#08	#09	#10	#11	#12	Fig. 21
CIP:Acrylic (1:1.5)	#13	#14	#15	#16	#17	#18	Fig. 22
CIP:Acrylic (1:2)	#19	#20	#21	#22	#23	#24	Fig. 23

Fig. 22 The measurement of the samples in Group A. The green boxes refer to figures. 21-23.

There are six different textiles in the experiment. Each of the six kinds of textiles was measured under four different conditions. In the first condition, the fabric is coated only with acrylic to determine the background absorption, i.e. with no RF absorption materials. Second condition had one CIP layer whose concentration is 1:1 and was brushed onto the textile. The third and fourth condition had concentrations of 1:1.5 and 1:2 respectively. After measuring the textiles, the best one of the six textiles will be defined and then will be used to make a new sample with CNT.

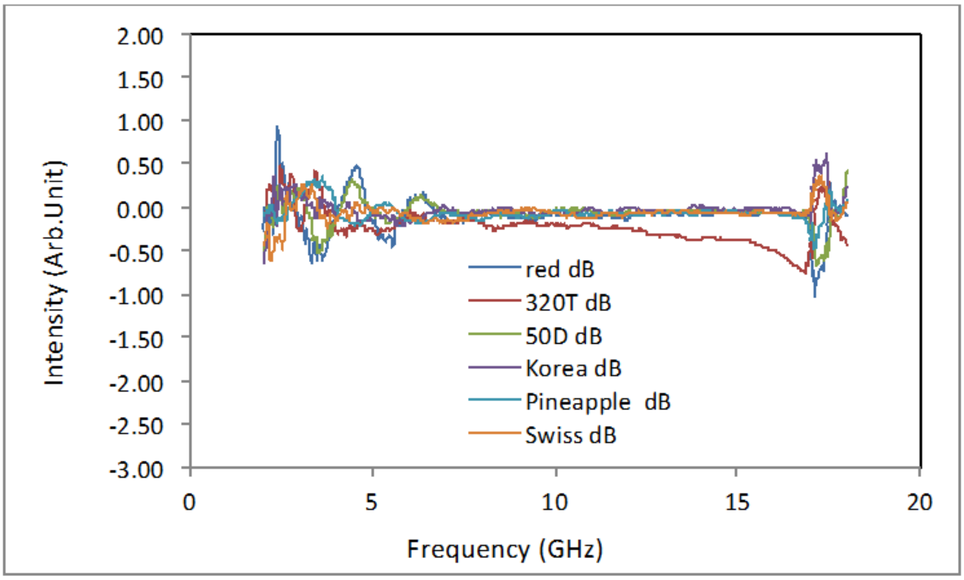


Fig. 23 Measurement of different textile with same concentration of CIP:Acrylic =1:1

The above figure indicates that the polyester 50D has the best absorption under the frequency field of 2.5GHz. At the same time, the above figure indicates that the Polyamide Swiss has the greatest absorption in the frequency of 2.6GHz to 3GHz. The Polyester 320T has the best ability of absorption from 8GHz to 17GHz. The Polyamide Pineapple has the greatest absorption in the period of frequency of 17.5GHz. The rest of the period reflects an average illustration of no significant absorption.

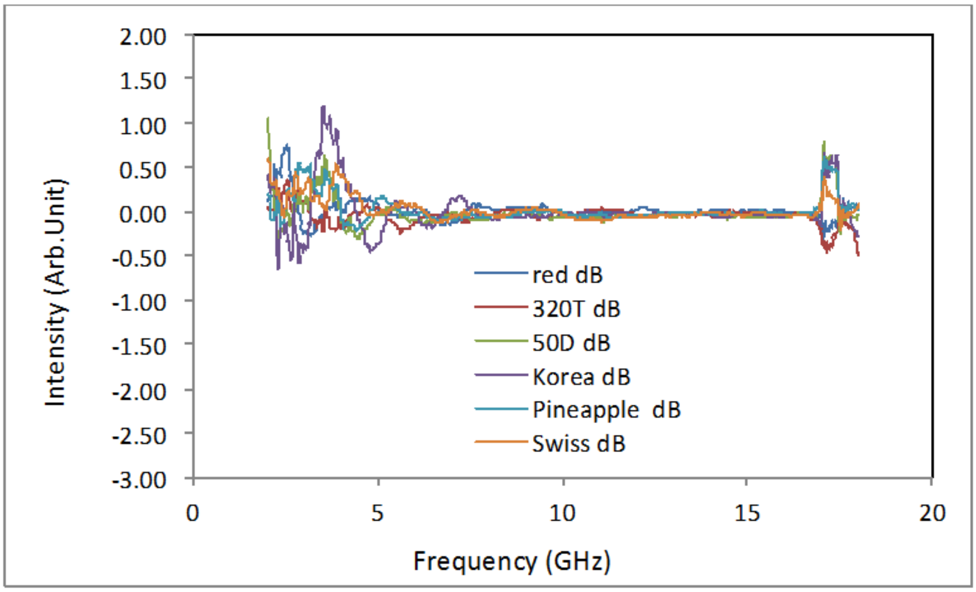


Fig. 24 Measurement of different textile with same concentration of CIP:Acrylic =1:1.5

The above figure indicates that the polyamide Korea has the best absorption under the frequency field from low frequency. The Polyester 320T has the best ability of absorption from high frequency. The rest of the period reflects an average illustration of no significant absorption.

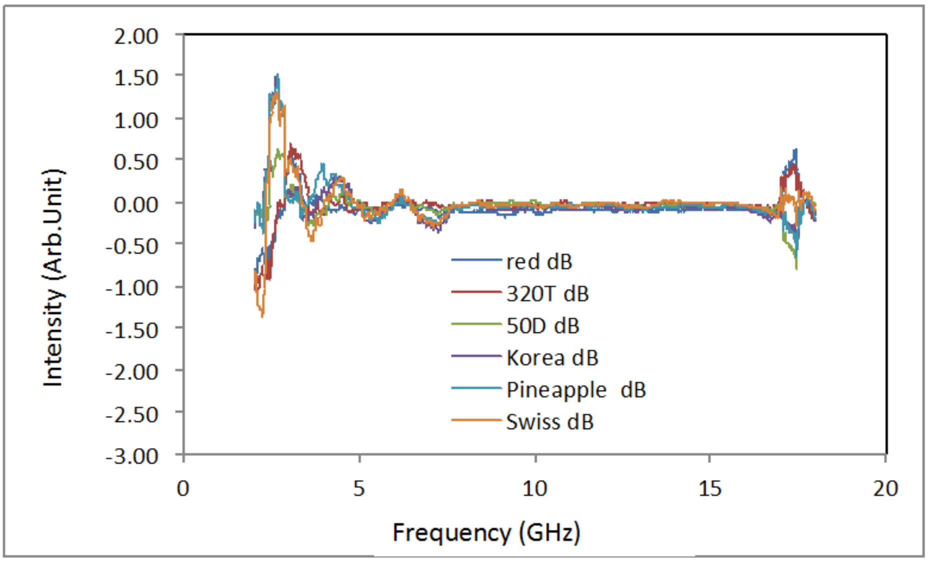


Fig. 25 Measurement of different textile with same concentration of CIP:Acrylic=1:2

The above figure indicates that the polyamide Swiss has the best absorption under the low frequency field from 2.5GHz to 4GHz. At the same time, the above figure indicates that the Polyamide Pineapple has the lowest absorption in the frequency of high frequency around 17GHz while the Polyester 50D has the best ability of absorption. The rest of the period reflect an average illustration of no significant absorption.

In summary, the three polyesters have better absorption performance than the three polyamides in high frequency range (16 to 17GHz). On the contrary, the three polyamides are better on average than the three polyesters in the low frequency range (2 to 4GHz). From the range between 5 to 15GHz, most of those samples ability are similar except sample＃8 which is polyester 320T with CIP(1:1 concentration). Sample＃8 has better performance in absorption ability than any other samples in the period of frequency which is 5 to 15GHz.

At the same time, all the three polyesters with concentration of 1:1 have higher absorbing ability in high frequency area. In low frequency area, the three polyester samples which have concentration of 1:2 have higher absorbing ability. However, the polyamide samples have greater absorption in average when they are brushed only acrylic layer. Based on the above results, I have chosen the polyester as the basic material with the CIP concentration of 1:1 in the following experiment.

There appears to be small differences between the fabrics and coating concentration. We speculate that the concentrations of CIP were too low in this case and are not useful for high frequency EM absorption. The addition of CNTs in group C, to improve electrical conductivity (and complement magnetic absorption), is explored next. Sample size was reduced to facilitate easier sample preparation as the supply of CNTs was limited.

(b). Sample list and results for Group B

Group B: The polyester fabric was chosen for this group as it performed the best in Group A. Six polyester textile samples with the various layers of the solution made of CIP and acrylic at a ratio of 1:1 (no CNTs). The details of the samples and solutions are listed below:

Table 6 Sample details of Group B

Textile Type	polyester
Textile Size	2cm x 2cm
Solution	Acrylic: carbonyl = 1:1 by 14.5g

In this experiment, we have cut the polyesters into 2cm x 2cm pieces.

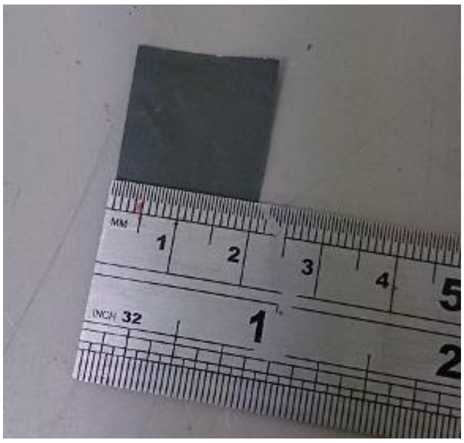
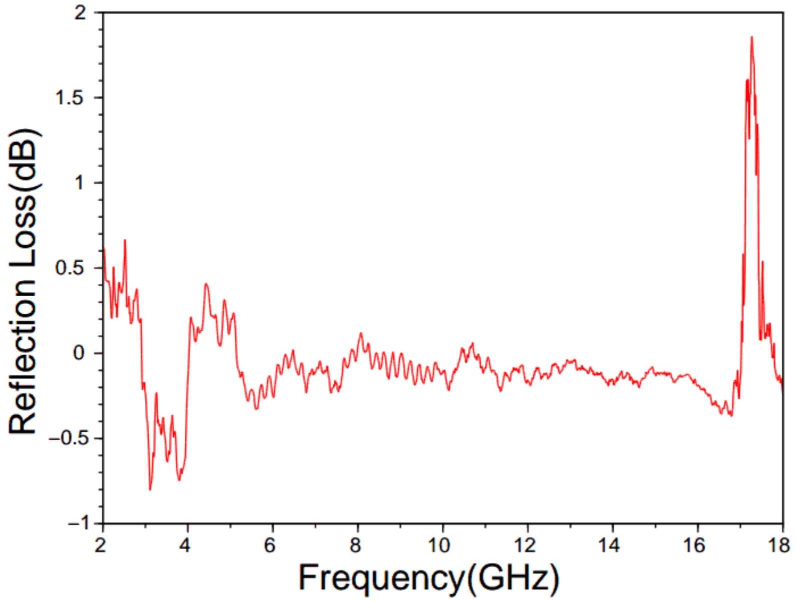


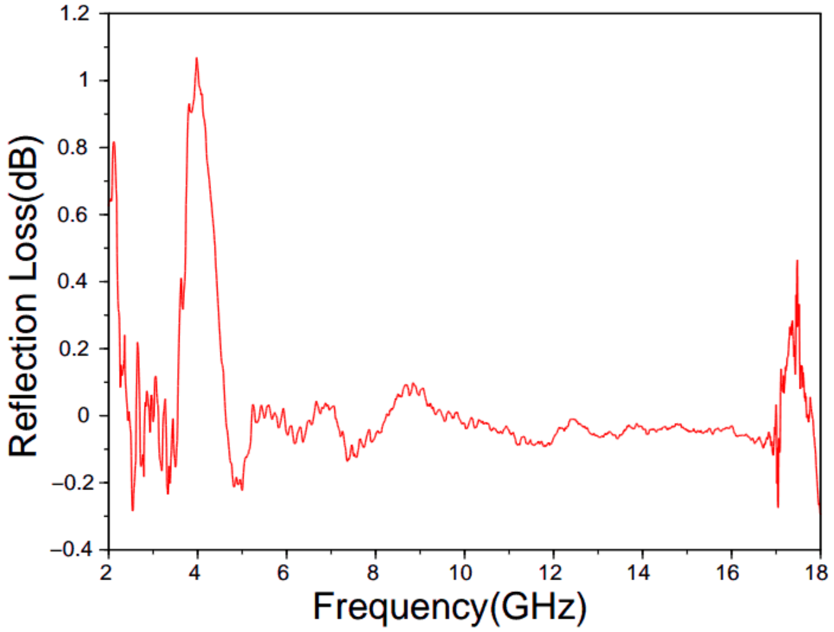
Fig. 26 A sample of Group B, coated with CIP

Table 7 In Group B, 6 polyester textile samples with the various layers of the solution made of CIP and acrylic

Sample	Original weight (g)	Layer number	Wet Weight (g)	Dry Weight (g)
#25	0.12	1	0.50	0.41
#26	0.12	2	0.70	0.62
#27	0.12	3	0.90	0.76
#28	0.12	4	1.01	0.91
#29	0.12	5	1.09	1.06
#30	0.12	6	1.15	1.10



(a)



(b)

Fig. 27 Results for the sample #25(a), #30(b)

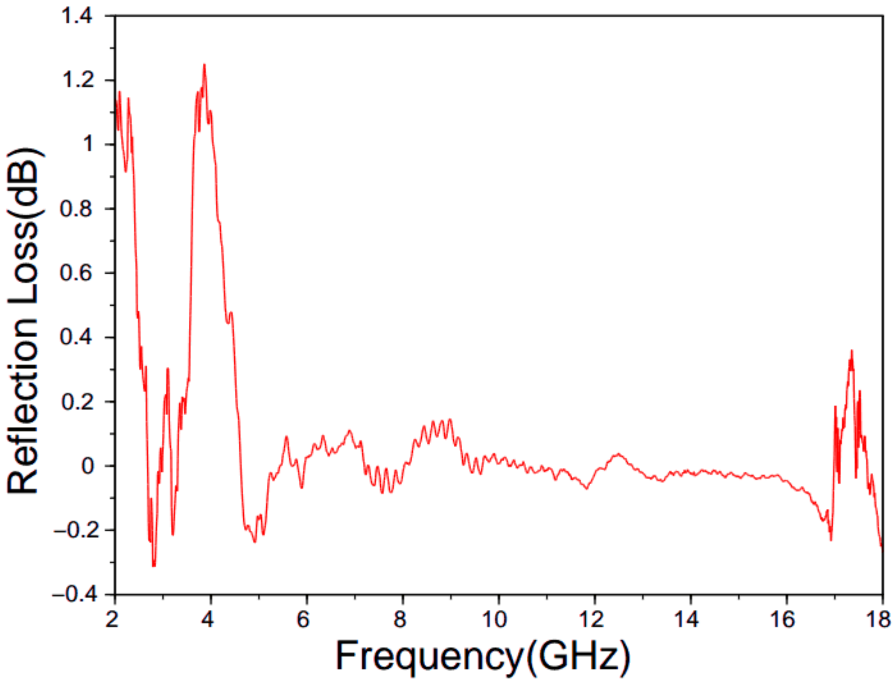
From the above figure we can see that the sample #30(6 layer of CIP acrylic) has a relatively high absorption at 4GHz because the reflection loses are high in this region. Sample #25(1 layers of CIP acrylic) has high reflection loses at around 17.5GHz indicating high absorption or transparency. In contrast, reflection loses are low between 3 and 4 GHz.

(c). Sample list and results for Group C

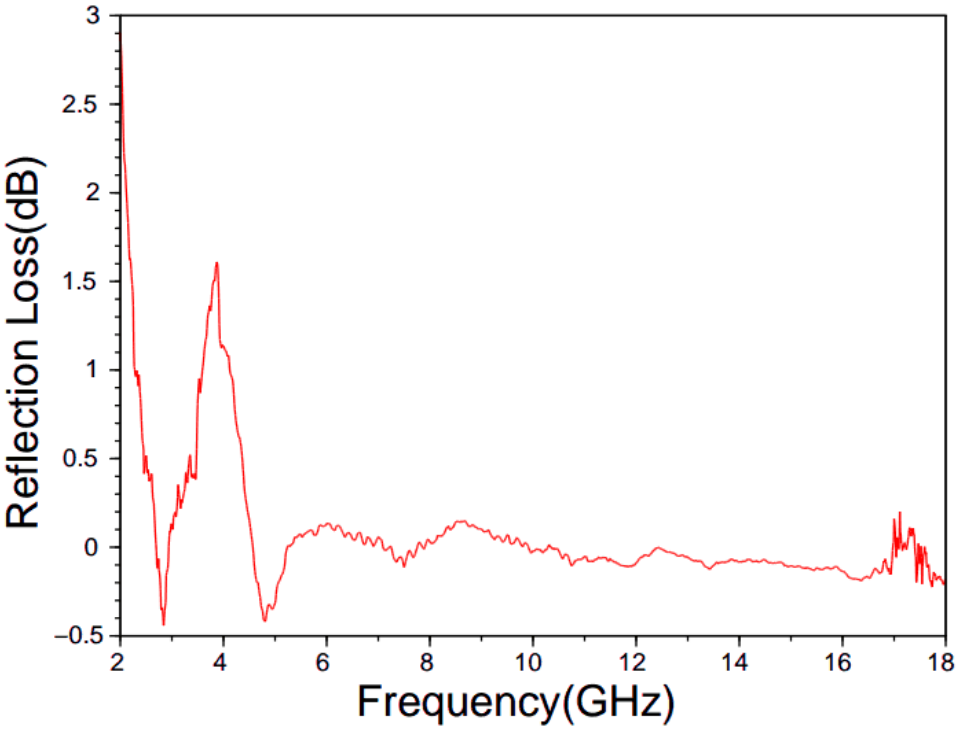
Six polyester textile samples with the various layers of the liquid made of CIP, acrylic and CNT.

Table 8 In Group C, 6 polyester textile samples with the various layers of the solution made of CIP, acrylic and CNT with IPA.

Sample	Original weight (g)	Layer number	Wet Weight (g)	Dry Weight (g)
#31	0.12	1	0.16	0.15
#32	0.12	2	0.26	0.20
#33	0.12	3	0.45	0.33
#34	0.12	4	0.51	0.35
#35	0.12	5	0.71	0.42
#36	0.12	6	0.93	0.57



(a)



(b)

Fig. 28 Results for the sample #31(a), #36(b)

From the above figure we can see that the sample #36(6 layer of CIP acrylic and CNT) has a better performance than sample #31(1 layers of CIP acrylic and CNT) especially in the area around Frequency 17GHz, indicating lower reflectivity.

When comparing the above figures, it is indicated that the sample with CNT has lower absorption at higher frequencies but higher absorption at 4Ghz.

These encouraging results indicate that some amendments can be done to the above experiment. After optimizing the textile and concentration, there is still the possibility of thickening the sample. In section 4.3.2. we further thicken the functional textiles and measure the absorbency.

4.3.2 Result of EM WSE Measurement

The previous experiments determined the basic elements of the following experiments: the material is polyester and CIP concentration is 1:1. The shielding effectiveness measurement is applied to this experiment, described in section 4.2.2, rather than the previous Arch method. This allows measurement of the absorbency.

The difficulty of using fabrics is that they require mechanical support during measurement. The solution for this issue is to brush one layer of acrylic on them first to stiffen them. The first four samples are made into one layer, 5 layers, 7 layers and 9 layers.

Table 9 The details of the four samples with different layers of CIP

Sample	Original weight	Weight with one acrylic layer	Layer number
＃37(F1)	2.58g	3.45g	1
＃38(F2)	2.63g	3.33g	5
＃39(F3)	2.66g	3.57g	7
＃40(F4)	2.66g	3.54g	9

From the below figure, we can see that in the range between 2GHz～4GHz and 16～18GHz, samples #39 and #40 have improved absorption. Sample #39 has the greatest absorbency. Then sample #38 is slightly better than sample #37 in this area. At other frequencies the differences are not obvious.

The results suggest that the absorbency versus thickness does not have a linear relationship. On the contrary, there is an optimal absorption layer which is 7 layers. Further work is required to explore this phenomenon.

From the results above, we can conclude that with the CIP acrylic polyester have an obvious absorption between 2～18GHz and a suitable concentration is 1:1 of CIP and acrylic polymer.

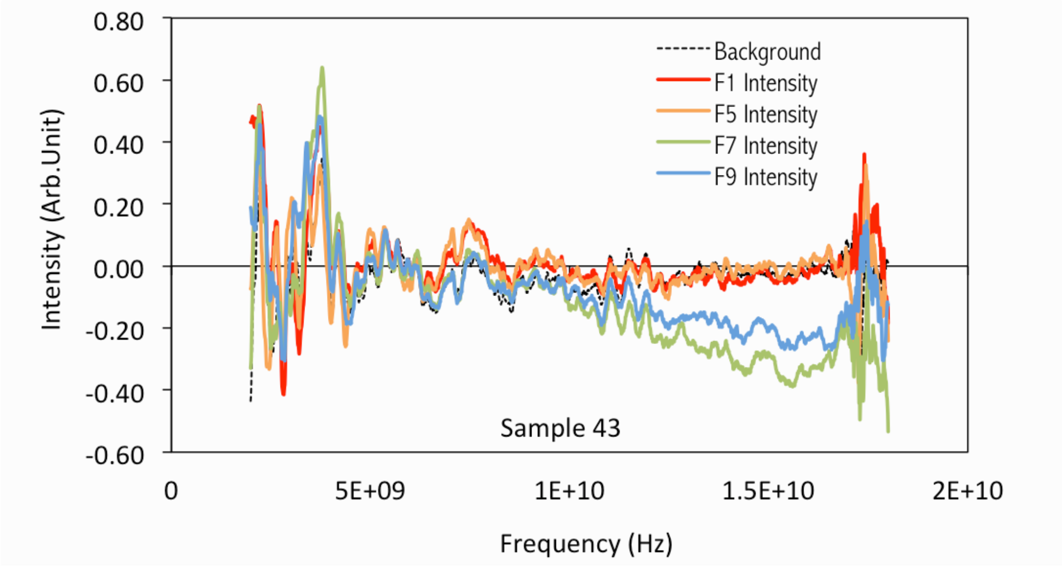


Fig. 29 Results of samples #37 sample with 1 layer of CIP , #38 sample with 5 layers of CIP, #39 sample with 7 layers of CIP, #40 sample with 9 layers of CIP.

Next we will explore the characteristics of functional textiles in lower frequency EM. The focus of this part of the work is on the nanoparticle heating effect.

4.3.3 Result of MIH Measurement

These feasibility experiments were conducted in three separate stages:

(a) Induction heating of wet solutions of Fe, Fe_3O_4 and commercial ferrofluid.

(b) Wetted fabric samples (IPA) using the solutions in (a) above.

(c) Dry fabric samples using the Fe, Fe_3O_4 and commercial ferrofluid particles.

The aim was to determine energy absorption of the samples by measuring the rise in temperature per unit time. Knowledge of the specific heat capacity of the liquid phase allows a qualitative comparison of the energy absorbed per second per unit mass of nanoparticles. Uniform heat loss rates are assumed for each sample measurement. The qualitative nature of the measurement is a result of the uncertainties, but were lessened by thermally insulating the sample holders. Equation (1) describes the energy absorption, whilst equation (2) gives the total power consumption which is the gradient of the c.m.ΔT versus ‘t’ curve (directly propionate to ‘T’):

$$U = c.m.\Delta T \tag{1}$$

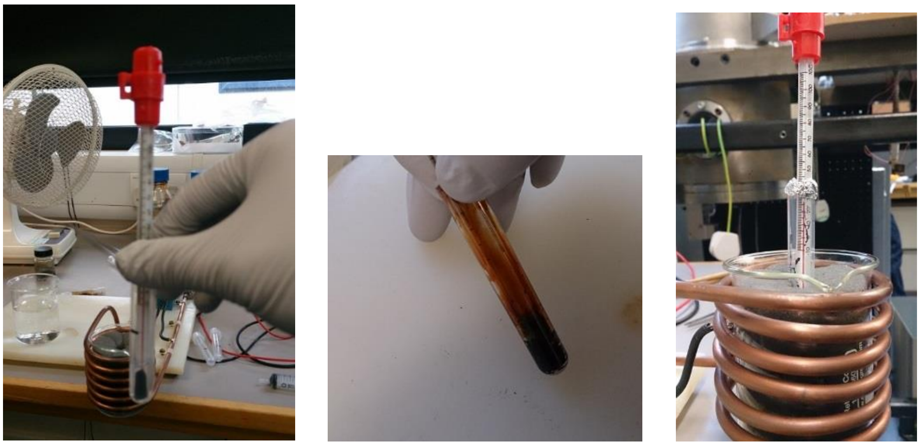
$$U/t = Power,\ W\ (J/s) \tag{2}$$

Where ‘U’(J) is the energy transfer, ‘t’ is the time in seconds, ‘c’($J.m^{-1}.K^{-1}$) is the specific heat capacity of the fluid, ‘m’(kg) is the mass and ‘ΔT’(K) is the increase in temperature. The heating power (U) applied to the nonmagnetic fluid is transferred by the nanoparticles within it. The power supplied by the nanoparticles in the magnetic field, per unit mass, is given by equation (3):

Heating Power provided by the Nanoparticles (HPN) =
Power transfer to fluid (U_f) / mass of particles (m_p)

$$HPN\ (W.\ kg^{-1}) = U_f / m_p \tag{3}$$

The HPN values for each type of nanoparticle is included in the results tables.
The volume of the IPA = 1ml
C for IPA = 2.5 $kJ.kg^{-1}.K^{-1}$
Mass of IPA (1ml) = 0.786g = 0.000786kg
Mass of each material = 0.1g = 0.0001kg
t = is taken from the table of results
The field coil that was used to heat the materials had a peak-to-peak field equating to 33mT and a frequency of 87.5kHz.
A search coil was used to determine the actual field values.



(a) **(b)** **(c)**

Fig. 30 The measurement of the temperature (a). the method of observing the temperature. (b). the liquid status of nanoparticle (Ferro-fluid) is under measurement to show the starting temperature; (c). the status when the tube put into the equipment.

The thermometer is inserted in the tube below, this is a good way to see the continuously temperature change during the heating progress. The tube and the thermometer will then insert into the hole of the beaker behind. The beaker is inserted with sponge and the size of the beaker fits the coil. And there is a piece of aluminum foil covering the tube in order to block the external air. This can make the sample stable and temperature accurate in the center of the measuring area.

(a). Results for induction heating of wet solutions of Fe, Fe_3O_4 and commercial Ferrofluid.

Table 10 The first experiment with different heating time and temperature data.

Particle/time	**1 min**	**2 mins**	**3 mins**	**5 mins**	**10 mins**	**HPN W/kg**
Iron carbonyl(15 ℃)	25C	30C	37C	47C	60C	1875
Ferro-fluid(15 ℃)	26C	35C	39C	45C	54C	1625
Fe_3O_4 (17 ℃)	19C	21C	22C	24C	28C	458

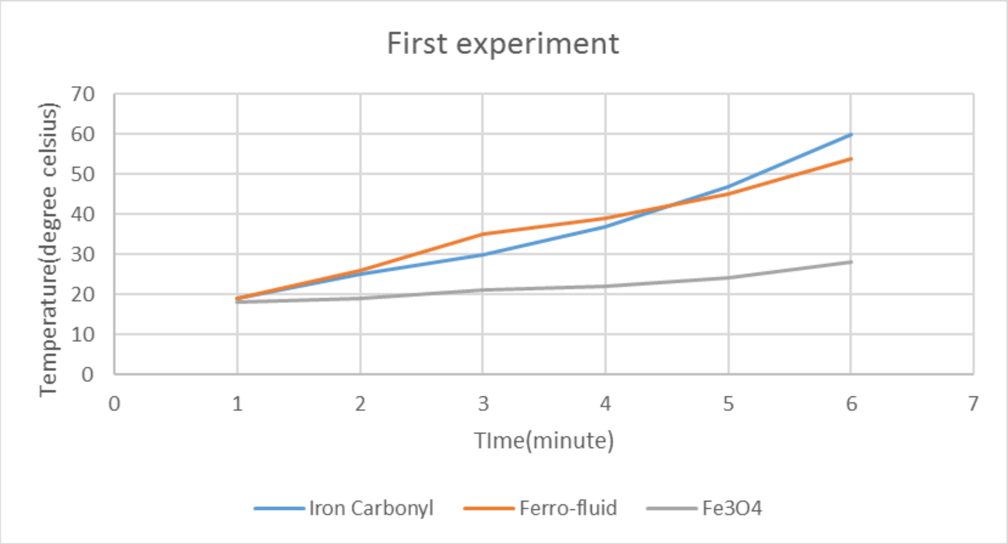


Fig. 31 The result of three liquid nanoparticles

In the above figure, it can be indicated that the in the first two minutes CIP and Ferro-fluid are almost the same efficiency of getting heat. Then Ferro-fluid becomes faster than CIP from 2 minutes to 3 minutes and then slow down its efficiency. After 3 minutes, CIP become faster than Ferro-fluid and reach 60 degree at 6 minutes while Ferro-fluid arrives 55 degree at that time. Fe_3O_4 has a slow speed of getting heat during the period and it only reach 28 degree after 6 minutes.

(b). Wetted fabric samples (H_2O) using the solutions

Table 11 The second experiment with different heating time and temperature data. (Unit: ℃)

Particle/time	**20s**	**40s**	**1min**	**100s**	**5mins**	**HPN W/kg**
Iron carbonyl(21 ℃) with clothes	25	28	30	33	40	1583
Ferro-fluid(19 ℃) with clothes	20	22	23	26	27	667
Fe_3O_4 (20 ℃) with clothes	21	22	22	22	22	167

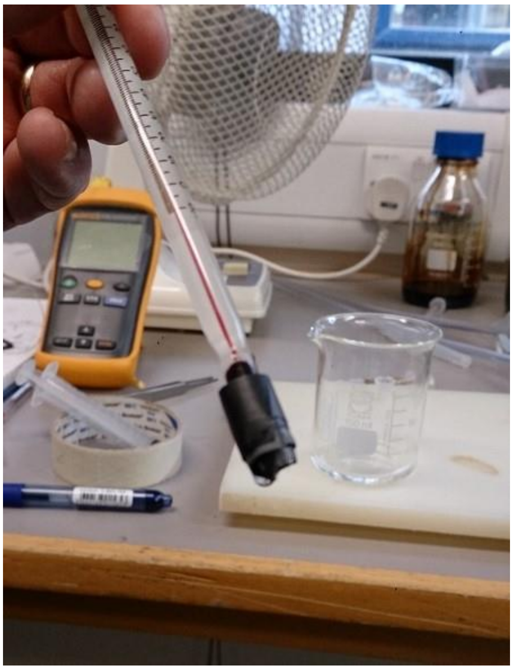


Fig. 32 Using small stick of liquid to cover the bottom of the thermometer in order to measure it

In the second part, there are two extra preparation, making of the small pieces of the textile soaked in the liquid nanoparticles and roll it on the bottom of the thermometer. The rest is same as the first experiment.

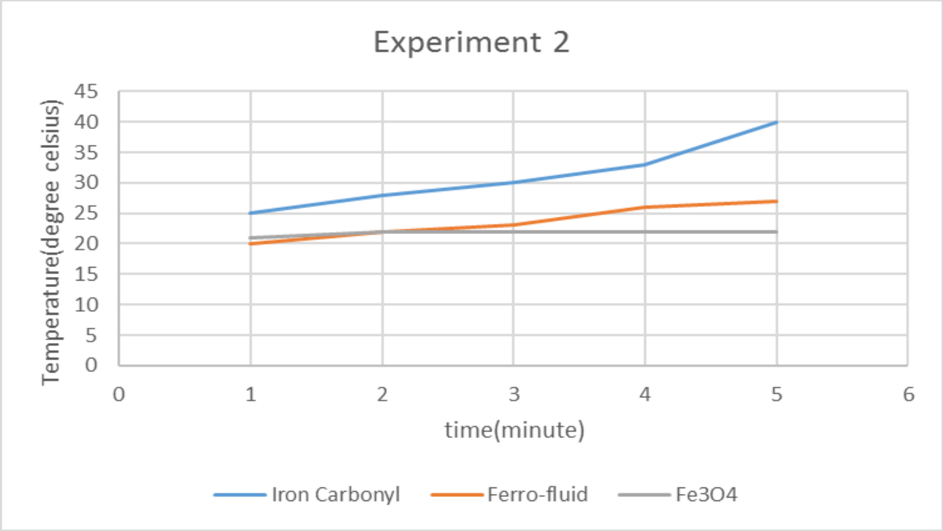


Fig. 33 The result of three samples with liquid nanoparticles

In the second experiment of this part, the CIP's ability of getting heat is superior to other two samples. It takes 5 minutes to make CIP sample into 40 degree. The Ferro-fluid sample and Fe_3O_4 sample have unexpected features of getting heat, which is it takes 5 minutes to make Ferro-fluid rise to 27 degree and Fe_3O_4 into 22 degree.

(c). Dry fabric samples using acrylic polymer to immobilize the Fe, Fe_3O_4 and commercial ferrofluid particles

The third experiment are almost the same process as the experiment above, the only difference is that the sample will be brushed on a layer of nanoparticle. The CIP sample can be cut from the previous part of experiment and the rest two samples need to be made by normal process as seen in the figure below:

We pull out the liquid and brush it onto the polyester and use two sticks to brush them averagely. After drying, it was cut into pieces to fit the size covering the bottom of the thermometer.

Table 12 The third experiment with different heating time and temperature data. (Unit: ℃)

Particle/ time	**20s**	**40s**	**1min**	**2min**	**3min**	**5min**	**HPN W/kg**
Iron carbonyl with clothes	20.5	20.5	20.5	20.5	20.5	20.5	N/A
Ferro-fluid with clothes	20.5	20.5	20.5	20.5	20.5	20.5	N/A
Fe_3O_4 with clothes	20.5	20.5	20.5	20.5	20.5	20.5	N/A

The reason why the curves go like that is because the inductive has no effect on the sample and the temperature of the sample goes down to the temperature of the water inside the coil.

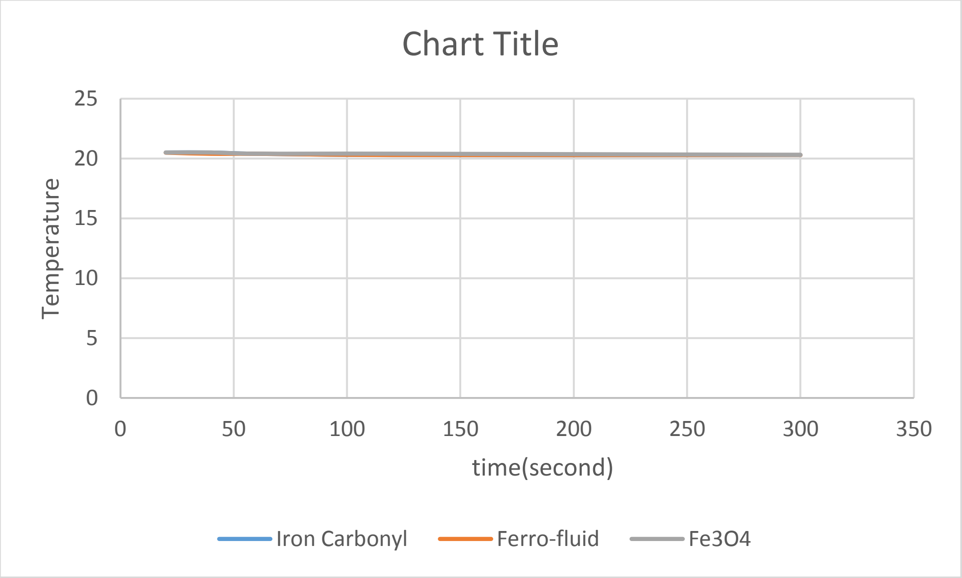


Fig. 34 The results of three samples with solid nanoparticles

The results of stage 1 show that heating was most pronounced for the Fe carbonyl in IPA fluid at 1875 W/kg, followed by the ferrofluid at 1625 W/kg. The Fe3O4 performed least well at 458 W/kg. In this case all the particles were in a fluid and free to move in all directions and this is likely to facilitate energy transference via particle vibration.

The results of stage 2 show that heating was most pronounced again for the Fe carbonyl in IPA fluid at 1583 W/kg, followed by the ferrofluid at 667 W/kg. The Fe_3O_4 performed least well at 167 W/kg. In this case the particles were partially constrained by the fabric which is likely to absorb some of the fluid and so restrict the mobility of the particles.

The results of stage 3 showed that heating was not measurable as there was no increase in temperature. In this last experiment the particles were free of fluids and so were very contained within and between the fibres of the fabrics. Heating was poor because the particles were unable to move or vibrate in the magnetic field and so could not transfer heat as rapidly as when they were in a free fluid.

The overall results indicate that particle mobility is important in the development of these composite materials. Furthermore, in stages 1 and 2, the Fe carbonyl particles exhibited greater heating effects than the Fe_3O_4 materials. This is because the particles are ferromagnetic rather than ferrimagnetic. In the former case the atomic magnetic moments are parallel rather than antiparallel, as is the case in the latter. The ferrofluid exhibited greater heating power than the Fe_3O_4 powder in IPA. Although both are Fe_3O_4 and ferrimagnetic, the ferrofluid is coated (i.e. with steric acid) to prevent agglomeration. The greater heating power of the ferrofluids may therefore be attributed to the greater mobility of its constituent particles when compared with the Fe_3O_4 powder in IPA.

We can conclude from the results of stage 2 that there is potential for a useful composite fabric and that the control of the particle mobility therein is critical to optimize its heating performance. This composite material is likely to take the form of a multilayered structure capable of retaining the liquid so as to prevent leakage and evaporation.

4.4 Summary

Three main measurement instruments were used in this part of the work, the arch test, EM WSE and induction heating. Several fabric types were used, in conjunction with CIP, Ferrofluids, Fe_3O_4 and acrylic polymer.

The optimal fabric textile was found to be polyester. The first results illustrate the effect of using six different fabric substrates in order to determine which are most effective at holding a coherent layer of CIP and acrylic coatings. Each fabric and coating was characterized to determine its ability to absorb electromagnetic energy for coatings with varying concentrations of CIP. There appear to be small differences between the fabrics and coating concentration. We conclude that the concentrations of CIP were too low in this case and are not useful for high frequency EM absorption. The addition of CNTs was further explored to improve the electrical conductivity (and complement magnetic absorption) and thus the microwave absorption.

Then the polyester fabric was chosen for Group B as it performed the best in Group A. Six polyester textile samples with the various layers of the solution made of CIP and acrylic at a ratio of 1:1 (no CNTs). Six layers of CIP acrylic has a relatively high absorption at 4GHz because the reflection loses are high in this region. One layer of CIP acrylic has high reflection loses at around 17.5GHz indicating high absorption or transparency. In contrast, reflection loses are low between 3 and 4 GHz.

Group C includes six polyester textile samples with the various layers of the liquid made of CIP, acrylic and CNTs From the experiment we can see that the 6 layer of CIP acrylic and CNTs has a better performance than 1 layers of CIP acrylic and CNTs especially in the region of 17GHz, indicating lower reflectivity. This work indicated that the samples with CNT have lower absorption at higher frequencies, but higher absorption at 4Ghz.

These encouraging results indicate that some amendments can be done to the above experiment. After optimizing the textile and concentration, there is still the possibility of thickening the sample and then re-measuring the absorbency.

The results of EM WSE measurement suggest that the absorbency of versus thickness does not have a linear relationship. On the contrary, there is an optimal absorption layer which is 7 layers. Further work is required to explore this phenomenon.

We have then explored the characteristics of functional textiles in lower frequency EM. The focus of the work is on the nanoparticle heating effect. Of the three materials studied at 87.5kHz, Fe carbonyl was found to be most useful when held in a fluid since it is ferromagnetic. The ferrofluid was also useful but relatively less magnetic as it is comprised of ferrimagnetic Fe_3O_4 . The Fe_3O_4 powder was least useful. Both the Fe carbonyl and ferrofluid show promise for future applications for the functional textile industry. The development of these materials is likely to involve the effective control of the mobility of the constituent nanoparticles within the textile.

Chapter 5

Risk management on the nanotechnology of functional textile made from magnetic nanoparticles

The two types of prospective functional textile using magnetic nanoparticles with different functions have been introduced and developed in the above experiments. In order to be clear, these two types of prospective functional textile are named Microwave-Absorption Textile (MAT) and Magnetic Heated Textile (MHT) in the following analysis of risk management. In this chapter, we will discuss the risk management on these two types of functional textile from the beginning of textile development to the textile promotion up to nanotechnology IP protection.

5.1 National Innovation system for Microwave-Absorption Textile (MAT) and Magnetic Heated Textile (MHT)

National Innovation system (NIS) is formed by national members to apply to all activities during an innovation process in a country. Since a NIS is an analysis on a national level, organization, technology and regulation are regarded as one integrated system. Academic, research institutions, government units, and industries are all major elements of a NIS. Here, we would like use one model of National Innovation system provide by S. J. Liu and Y. J. Liu as seen in the reference of [177] and the below figure.

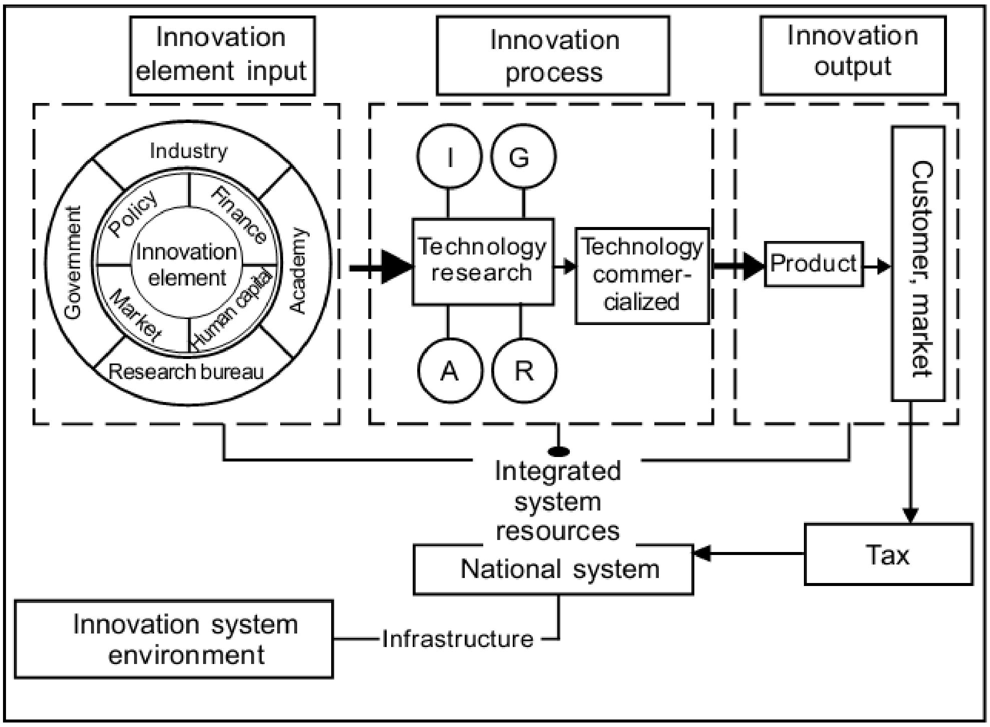


Fig. 35 National Innovation System.[177]

The above figure shows that the numerous factors affect enterprise innovation, and national policies will directly influence the driving force of innovations. Here, the origin of these factors will be discussed in detail and we will also briefly study these factors applying on Microwave-Absorption Textile (MAT) and Magnetic Heated Textile (MHT).

5.1.1 Innovation element input for MAT & MHT

The innovation element input include: 4 types of organization: industry, government, research bureau and academy; and 4 types of resource：policy, market, finance, human capital.

(a). Industry

The network structure created by NIS forms an agglomeration which serves as an important factor in nurturing the spirit of entrepreneurship.

Any innovation enterprise must have human resources, research funds, suitable markets, development potentials, fundamental technologies, technology trades, the distribution environment, and IP.

The prospective industry for the microwave-absorption textile (MAT) and magnetic heated textile (MHT) will be the main organization to develop, commercialize and protect the nanotechnology used on these two types of functional textiles. It is very important for industry and public to let the industrial organizations follow NIS. Industry should firstly make sure that all material used in the development of functional textiles including magnetic nanoparticles, textile and solution are safe. Also, industries should precisely approve the development processes so as not to create new risks for health and the environment.

(b). Government

The Government is the organization for issuing the rules, regulations, laws, property rights and national innovation system for the risk management on nanotechnology. These rules, regulations, laws, policies and governmental supports can affect whether or not a new product can be successfully developed and commercialized [178]

The government support for the microwave-absorption textile (MAT) and magnetic heated textile (MHT) is also a vital point in the NIS. The government should create some institutions and rules in order to make sure the industrialization of magnetic nanoparticles, textile and solution does not have any hazardous risk.

(c). Research bureau

The research bureau for the microwave-absorption textile (MAT) and magnetic heated textile (MHT) should make sure that research is safe and the funding either from government or informal organizations should be ample even for protracted development. The research bureau should do a series of tests to make sure the magnetic nanoparticles earmarked for commercialization are not hazardous. Furthermore the research bureau should ensure there is enough interest and investment in magnetic nanoparticle clothing market, as well as using precautionary forecasts to avoid any risks that might happen in the area of magnetic nanoparticles.

(d). Academy

Academic organizations are the place where emerging technology is instigated and developed. For the microwave-absorption textile (MAT) and magnetic heated textile (MHT) it is also the bedrock of all the NIS system. Once the academy sets up some projects and labs with support from government, research associations or industry, it is an ideal resource for researchers to focus on nanotechnology development, its commercialization and risk factors from the beginning of development through to bringing it to market.

(e). Policy

The policy is made by government to focus on making industrial development of technology more feasible and controlling the risk during development and commercialization. With the support of government policy, industry’s funding of innovation can be drastically reduced and business operations can be enhanced. Policy for the microwave-absorption textile (MAT) and magnetic heated textile (MHT) is essential in the NIS system. The patent of these two textiles is under threat of being stolen and copied, so support from policy is essential. At the same time policy can offer the right to manufacture the appropriate products. For example, magnetic nanoparticle clothes need the support of IPR protection or it will encounter the risk of plagiarism.

(f). Market

Creating a successful market for goods and service used by technology innovation is the purpose for both industry and government to obtain profit and public benefit. To achieve a successful market for the microwave-absorption textile (MAT) and magnetic heated textile (MHT) will judge whether nanotechnology is able to service expectations of its enhanced properties. The financing of a magnetic nanoparticle company will reflect the research and manufacturing costs of product development as well as the on-going research and manufacturing innovations. Conversely, if the market demand is poor, the financial risk of producing magnetic nanoparticles would be significant.

(g). Human Capital

Human capital is one of the most important factors when determining the risk of nanotechnology development and commercialization, and also is the first priority in controlling that risk. For the nanotechnology applied in MAT & MHT, human capital should be considered in detail because different products and different processes in the industry need to be treated individually, but with the same goal of minimizing risk.

(h). Finance

Finance connects all the other three organizations(Policy, Market and Human Capital) and is the basis for the development and commercialization of any emerging technology. For the microwave-absorption textile (MAT) and magnetic heated textile (MHT) there is no doubt that finance is a vital part in the NIS element input. Finance's function to any firms cannot be easily replaced. Finance is the connection to all the other elements during the cooperation. For example, the financing of a magnetic nanoparticle company has to consider research and manufacturing costs, which need to be reviewed constantly in order to reduce the risk to health and the environment during the development and commercialization of emerging technological processes for magnetic nanoparticles.

5.1.2 Innovation process for MAT & MHT

In the above figure, the second section of the NIS is the innovation process, which is effected by four innovation elements: Industry, Government, Research and Academy. Here, we will only focus on technology development & research and technology commercialization by assuming no risks from these four innovation elements.

(a). Technology Development & Research

Generally, development risk exists in any products, such as the practical application is not broad, the techniques are complex or there is a hazardous effect on the environment.

My experiment can be assumed to be the development period in the Innovation process of National Innovation System. An example of the risk I encountered during the experiment all the time was with the use of Carbonyl Iron Powder which was used in almost every experiment.

<u>Description of the Substance</u>: Iron powder (Carbonyl Iron).

Supplier and Product Name: BASF The Chemical Company.

Activity:

Only wet solutions of Fe + isopropyl alcohol (IPA) will be used in the laboratory. Users will mix with acrylic paint which will then be applied to a fabric using screen printing equipment, brushes, applicator paddles or hand rollers. The solutions will be allowed to dry in air and then further coated with a layer of acrylic paint.

Location: This product is to be used in D015 and other controlled areas under the supervision of trained staff.

Those Involved in the Activity: An MSc student and staff members.

Hazards: In halation of dust particles, dust in eyes and on skin. Combustion of dry powder if exposed to naked flames. See the safety data sheet for further guidance.

The risks associated with this activity: There is little risk associated with this activity if the precautions, outlined below, are followed. The frequency of exposure and the quantity of product used, are relatively small. Ingestion, inhalation and absorption via splashes to the skin, or eyes constitute a low risks.

Steps taken to reduce Risks: Primarily, the approach here is to follow good laboratory practise when handling chemicals. Additionally:

- Nitrile gloves and goggles will be worn during sample preparation, when required.
- A face mask will be worn by staff who will add IPA to the iron powder before students arrive. A magnet will be used to capture any dust that is created, since iron is magnetic.
- Any spills will be wiped up and stored in polythene bags for disposal in the same manner as other chemical waste.
- Only very small amounts of the product will be used, minimising exposure.

- This activity will be performed infrequently, thus further minimising exposure.
- Once coated with the product, the sample will be placed in a sealed bag.
- Gloves will be worn, when handling the prepared samples. Once SEM images are obtained, the samples will be returned immediately to the sample box.
- The sample box will be sealed in a plastic bag for storage.
- The product will be placed in a locked laboratory.

The advice included in the safety data sheet will be followed if direct contact with the material occurs, and one of the university first aid providers will be notified. The incident will also be recorded via the accident reporting procedure.

(b). Technology Commercialization

The second part will talk about the nanoparticle samples after it is commercialized. With the experience of my experiments, there is no doubt that a lot of future research is needed so it is a good idea to start with small sized samples as a first step. These can be tested if no forbidden hazardous technique is included and the sample size can be enlarged with every successful test to a point to ensure that commercial scale production would be safe to human health and the environment. This applies to the MAT and MHT and once the testing methods follow NIS or other risk management models and satisfy the benchmarks for the risks for health and environment, the nanotechnology used in MAT and MHT is commercialized and ready for marketing.

5.1.3 Innovation output for MAT & MHT

Innovation output is the last section of NIS, but there are still a lot of areas with unexpected risks for health and the environment. Even if the products are sold in the market, some risks may emerge over the time goes which may require regulatory changes. This needs to be managed by risk management methods such as life circle, labeling and such like. For example, the optimal conditions of the magnetic nanoparticles for MAT and MHT have some limitations on the temperature and moisture. If such products are used in conditions outside of such limitations, users should be told what kinds of risk might emerge. For example, MAT might lose its magnetic property when it gets close to high temperature items such as fire; this would bring about the loss of its microwave absorbing ability leading it losing the efficacy of the function for which it was designed.

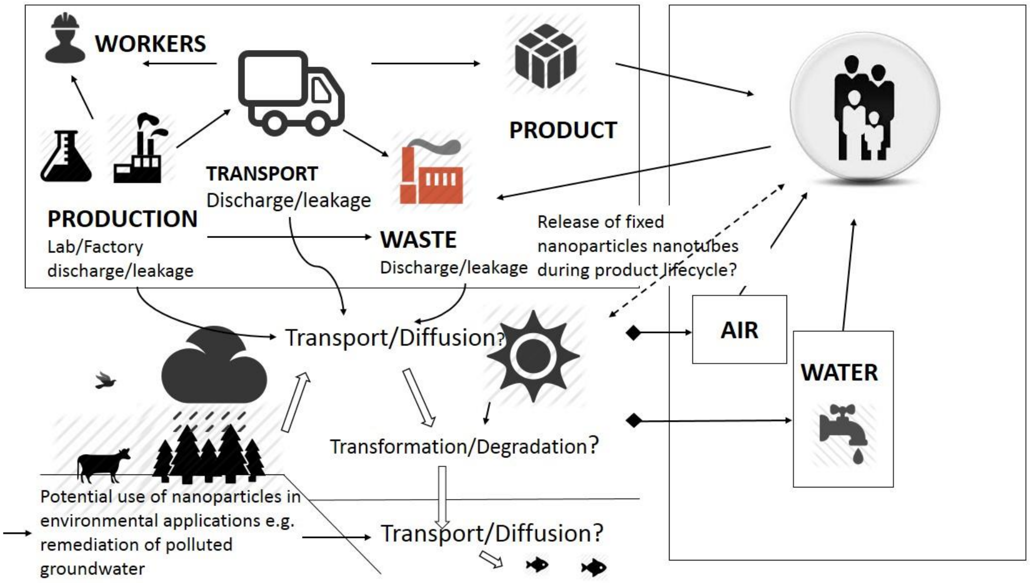


Fig. 36 Possible exposure routes for nanoparticles and carbon nanotubes

The above figure shows an idea of how the magnetic nanoparticles used on the MAT and MHT probably expose risk. The possible exposure routes are shown in the figure above. Although the bulk substance is not toxic, nanoparticles' size may cause toxic properties. Human beings may be endangered when those nanoparticle gain access into the body through the intestinal tract, skin and lungs. Because nanoparticles are easy to agglomerate, they will become less reactive and are hard to degrade in nature. In order to control the risk, nanoparticles should be treated carefully and under restricted conditions.

5.2 Intellectual Property Rights (IPR) for Microwave-Absorption Textile (MAT) and Magnetic Heated Textile (MHT)

Intellectual Property Rights (IPR) for magnetic nanoparticles is also a vital point. In this chapter, further serious outcomes will be explained if the application of IPR does not function to its optimum. As presented in Chapter 3, illegal imitations and counterfeits of products can cause destructive results beyond imagination. Poor management of nanotechnology could be a health and environmental pollution problem that has global reach.

In the case of the two textiles investigated in this thesis, MAT and MHT, the consequences of a counterfeited manufacture without the backing of thorough regulation is hypothesized in the next section.

5.2.1 IPR for MAT

There are many potential risks in the unregulated production of MAT through the violation of the IP. Below are three examples:

(a). Plagiarizing IP leading to using dangerous nanomaterials

Magnetic Block Textile may have hazardous effects if the plagiarist does not know the application method or the suitable material to use. The plagiarist may brush some particles which look like magnetic nanoparticles on to other textiles which would mean lower production costs due to the use of inferior materials and textiles, but the inappropriate product may do harm to people's organs such as the lungs and heart. Added to which, if the inappropriate nanomaterials they use are not embedded well on the textiles, the particles may be spread into the public water system, which would cause unexpected disasters. Thus it is important to enforce IPR in order to prevent substandard manufacture by unqualified industries and individuals.

(b). Plagiarizing IP leading to wrong functions

At the same time, plagiarists' lack of knowledge may well lead to the final MAT product being ineffective in delivering its enhanced properties such as the blocking of special waves.

(c). Plagiarizing IP leading to dangerous development

If the plagiarists plan to deliver more functions by developing the IP, a new and dangerous risk would appear due to neglecting the critical risk management procedure of the innovation process. For example, the development of MAT with the wrong risk management practices would lead to the plagiarists choosing the wrong types of magnetic nanoparticles and solutions for the particular blocking-wavelength of microwave.

5.2.2 IPR for MHT

(a). Plagiarizing IP leading to using dangerous nanomaterials

In the development of MHT, manufacturers are required to carefully match the specific types of textile with the particular magnetic nanoparticles in order to secure the nanoparticles strongly. Therefore lack of adherence to researched and tested patents and the use of the wrong materials and textiles are critical errors in nanomaterial development and manufacture. Contravention of IP and manufacture without the backup of thorough research and patented techniques could very easily lead to serious hazards for public health and the environment.

(b). Plagiarizing IP leading to wrong functions

Incorrect manufacture of nanomaterials by unauthorized companies is likely to lead to the properties of enhanced textiles not being realized. Textiles that are supposed to generate heat may not function to the correct levels. For example, MHT can be used to make a carpet which can prevent a water tank from freezing in cold weather or can warm up a fuel tank before initiation. Incorrectly manufactured MHT could culminate in under or over performing, which could lead to explosions in the case of overheating.

(c). Plagiarizing IP leading to dangerous development

In relation to MAT and IPR, unauthorized manufacturers of such textiles will certainly find it virtually impossible to make correctly without the support of the accredited technological infrastructure.

5.3 Risk management for MAT and MHT in China

China is currently a prolific producer of textiles with both the largest number of textile manufactures and the largest clothes market. There is enormous demand for the textile, especially functional textiles with new technology due to people seeking more purposes from clothes. For Chinese consumers, these special features integrated in our textile products can meet their specific demands on functionality. This is due to the fact that as one of the largest developing countries, China’s rapid economic development is associated with various ecological and environmental problems which are seriously endangering the health and quality of life of its residents Among these ecological problems, dust pollution and radiation pollution from electromagnetic waves are quite severe nowadays, which has raised awareness among the public and the government. Therefore it is expected that new nanotechnology textile products will receive much attention from Chinese clothing producers and consumers and the market potential is likely to be very large.

However, as China has a multitude of textile companies, small and large, the potential of imprecise manufacture of functional textiles is quite high hence the imperative nature of having a workable risk management strategy in place at all levels. Here, we will focus on the risk management of NIS and IPR for MAT and MHT in China.

5.3.1 Target country (China) analysis of NIS

China is making great efforts to encourage R&D and innovation such as building R&D centers and networking with indigenous firms. In order to encourage both indigenous and foreign R&D and innovation and building links between them, the Chinese government has done a lot ranging from offering financial support and reducing tax upon foreign assets, to improving intellectual property right protection systems and condemning illegal imitations. During this process, the Chinese national innovation system and intellectual property right system are playing a key role in providing incentives and returns to investors of R&D.

The National Innovation System in China plays a very important role for emerging technologies such as nanotechnology. For the researched textiles, Microwave-Absorption Textile (MAT) and Magnetic Heated Textile (MHT), it is extremely vital to apply NIS in China even at the very earliest stages of nanotechnology development.

(a). Government of China

Government, one of the four innovation element inputs, plays an important but complicated role in China because China has an inter-ministry system (the Ministry of Science and Technology, as State Council of Science and Technology) at the national level and then province-level (Bureau of Science and Technology, Bureau of Education and so on) and county-level systems which work at the local level but are answerable to the national strategy.

For the development of MAT and MHT in China, the researchers or research organizations should not only follow the rules at national level but the provincial and county level systems too, which might cause the risk of confusion with the application of the regulations. A typical scenario may be that a county-level system or local council might permit the manufacture of MAT and MHT using the magnetic nanoparticles without a full assessment in order to create more job opportunities in the local area. Similarly, at a higher level, there is likely to be a lack of resources to check every manufacturer across the country that they are following all critical risk management procedures during the manufacture and development. Both examples show potential risk from the issue of government as one of the four innovation element inputs.

(b). Industry of China

Industry in China is well established but still lacks the strong capability of research & development generally in some industrial sectors. This has the potential to cause an unstable industrial environment, so if, for example, the textile companies who manufacture MAT and MHT cannot cooperate with the magnetic nanoparticle supplier well, the final product will be compromised.

(c). Research Bureau of China

The research bureau of China is a complex combination of several organizations, not only research committees led by state-level organizations like the Ministry of Education, the Ministry of Finance, the Ministry of Industry and Information Technology, the Ministry of Agriculture, the National Development and Reform Commission, Chinese Academy of Sciences, Chinese Academy of Engineering and the Natural Science Foundation (NSF) Commission, but also a lot of research committees led by provincial level organizations. There is risk that these research bureaus at national and provincial level will decide on the research directions and the allocation of research funding by understanding the research trends and risk management differently. For MAT and MHT, these research bureaus might make research strategies based on their own interests, which might cause incompatibility at a national level and also unexpected health and environment problems.

(d). Academy of China

The Chinese education system is famous for its exam-oriented education. Students accumulate theoretical knowledge in a short time frame but lack practical learning. When MAT and MHT are in the developmental stage, those who turn from students to researchers may not have enough experience of doing experiments required by the process. This will cause a delay in the development process.

Those four elements above are important either in innovation input and innovation process. There is no reason to diminish the importance of any of them.

(e). Market of China

There may be a case for developing a good market for MAT and MHT by setting up a new R&D center/lab in China and working in collaboration with the R&D headquarters and lab facility in the UK in order to keep developing new nanotechnology applications in functional textiles.

(f). Policy of China

Chinese policy should provide enough support to protect MAT and MHT's patent from being stolen or being plagiarized. China government should make a broad series of policies to secure nanotechnology researched in academic institutions and industry and prevent violation of patents.

(g). Technology Development, Research and Commercialization

With strong and effective NIS support by innovation input, the risks associated with both new product development (technological risks) and commercialization (market risks) can be managed to a certain degree.

For the development of MAT and MHT, a research facility in the institutes or company could be set up firstly in order to train the researchers with a comprehensive risk assessment and set up the full range of risk management for the development. The magnetic nanoparticles used on MAT and MHT can also be fully researched in order to apply the full risk controlled system and NIS thereby reducing risk to a minimum.

For the commercialization of nanotechnology of MAT and MHT, fully trained researchers could easily transfer knowledge and experience of the risk management to manufacturing personnel. The manufacture also should follow the regulatory NIS and risk management to reduce the health and environment problems possibly while applying the magnetic nanoparticles onto the textiles.

With such measures it is possible to control the risk during the innovation and manufacturing processes of nanotechnology in China.

5.3.2 Target country (China) analysis of IPR

The major risk in the production of MAT and MHT is that unauthorized producers who do not have a complete knowledge and experience of risk management misuse not only the patented technology, but also neglect the risk management aspects of working with nanomaterial. The owner of the technology protects his ‘right’ to the knowledge through Intellectual Property, but also protects the interests and returns of innovation as well as the need for a full risk assessment, which in turn makes nanotechnology safer.

In China, IPR protection is very important but difficult both for industry and government. However, the risk of nanotechnology and nanomaterial has the potential to cause disaster to health and our environment if researchers or manufacturers do not control the risk during the development and production.

For the magnetic nanoparticles used on the MAT and MHT, the Chinese government should license certain companies to produce and sell magnetic nanoparticles, and track all researchers or companies who buy the magnetic nanoparticles through labelling systems. Research facilities and commercialized companies should have certification for using the magnetic nanoparticles during the development and production. All products and prototypes should be measured by authorized organizations. All these processes and information should be included in the IPR, which can be used by people or organizations who have obtained full training of risk management. Moreover, firms should liaise with local patent offices in China to acquire information on the development and dynamics of IPR protection in the industry. Furthermore, they should monitor closely potential illegal imitators and counterfeit products emerging in the market and report those to the local patent offices in order to protect their own benefits and returns in time and counter the unethical codes of conduct in such business activities. This can also help to prevent potential health problems and environmental issues arising from the improper usage of MAT and MHT products.

5.4 Summary

In summary, the National Innovation System (NIS) and Intellectual Property Rights (IPR) applied to Microwave-Absorption Textile (MAT) and Magnetic Heated Textile (MHT) has been studied. Valuable approaches have been proposed and discussed with the aim to control the risk during the development and the commercialization of the specific nanotechnology on these functional textiles. We have also researched the risk management of manufacturing these functional textiles in China with adherence to the National Innovation System and with the protection of Intellectual Property Rights. The results show that it is possible to develop functional textiles into commercial products in the future with well controlled risk management during product manufacture.

Chapter 6 Conclusion and Future Work

6.1 Conclusion

The following are the main results of this work.

This research work combines nanotechnology experimentation and risk management as a multidisciplinary study between the Department of Electronics and the York Management School, which is the very first joint programme. Based on the nanotechnology experimental results and the risk management analysis, it has been demonstrated that the utilization of nanotechnology in improving the function and properties of textiles like microwave absorption and magnetic heated is viable, and that there are useable models of risk management – National Innovation System - that control the risk during development and commercialization. Added to which, Intellectual Property Right protection will significantly improve the risk management infrastructure.

In detail, an introduction of nanoparticles is first presented. It generally talks about the development of nanoparticles and advantages of nanotechnology. Then risk and risk management is discussed, emphasizing the importance of using risk management in any processes from creation to commercialization. Thereafter a definition of functional textiles is introduced followed by an appraisal of nanoparticles in the following chapter. Magnetic nanoparticles, textile development and risk management are the three main themes of this thesis.

In Chapter 2, the development and the current application of functional textiles by various forms of nanotechnology is introduced. There are several aspects of application such as protection, reinforcement and health. Each aspect is supported by examples. This is followed by the challenges and opportunities of the examined nanoparticles.

In Chapter 3, risk management is divided into three parts: The risk management principle, the two models of risk management and risk management in China. Traditional risk management and precautionary risk management are the principles in the thesis. The concept of the National Innovation System and Intellectual Property Right are used. NIS is adopted for traditional risk management while IPR is for precautionary risk management.

With theoretical support, some experimental works are done in Chapter 4 which is important to the thesis. The appropriate magnetic nanoparticles are selected and made into textile samples; after that the results are shown through measurement, and according to the features they have, two products are put forward as viable for further development, MAT and MHT. They are functional textiles in that MAT can absorb waves of certain frequencies and MHT can create a self-heating function. Although the experiments do not have patents or prototypes with details, they indicate the basic methodology of production within the NIS framework and a good direction for the commercialization of nano-enhanced textiles.

Chapter 5 looks at the risk management of the two created products: MAT and MHT, using the related NIS and IPR to support the analysis of it. This chapter goes on to consider risk management that the development and production of MAT and MHT might face in China.

In order to reduce the traditional risk and precautionary risk, every element of the NIS should be utilized while IPR’s role is not only for protection of commercial value of nanotechnology development but also for protection of the associated risk of manufacturing procedures. This thesis provides some appropriate methods of risk management for R&D companies or organizations and precautionary advice in respect of IPR.

6.2 Suggestions for future work

Textile development using nanoparticles and integrated scientific systems is an incredible breakthrough for the textile industry and has far reaching implications for the industry, and for the individual since textiles are an integral part of everybody’s life. Textiles are very suited to enhancement through the use of nanotechnologies. At the core of this idea is that clothing is an extension of physiological characteristics and so the combination of clothing and nanotechnology could be interpreted as a connection and interaction between men and machine. In the future a jacket, shirt or dress could be a platform of communication and information, protecting you and helping with your work. Increasingly people and the environment will embrace the properties that functional textiles can bring. With the development of MAT and MHT, people could live in an environment shielded from wave interferences by wearing clothes made of MAT. Similarly people can get food from hot ovens just with the use of gloves made from MHT.

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