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Review

Nanotechnology: The future of fire safety

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ABSTRACT

This study reviews fire protection developments and explores the applicability of nanotechnology for mitigating emerging issues. There are many types of fire retardant materials that can mitigate damage and compartmentalize fire, but nanotechnology has been shown to be more effective in providing adequate protection against destructive fires. This study further examines nanotechnology and how it can be used to minimize fire damages to property and personnel. Nanotechnology is based on miniaturized particles in the order of 10^{-9} in size, which makes it very useful because the materials can be manipulated for beneficial use beyond the capacity of regular materials. This in turn creates a stronger light-weight material that can be used in many fields. In this instance, nanotechnology can be used for fire protection. This study additionally reviews some of the disadvantages with the use of nanotechnology. Presently, there has been minimal research identifying the chronic effects from nanotechnology exposure, preliminary studies of nanoparticles show that there are side effects that mimics the overexposure of asbestos. When nanotechnology penetrates the skin and lung tissues of workers that are exposed to it, it can cause spores to grow in the lungs and can be lethal if overexposed. Nanotechnology has a few concerns but if it is tested and applied properly, it can become the future in not only fire safety but healthcare and manufacturing.

1. Introduction

Fires within the United States have been a problem for several years. The total number of structure fires within the United States between the years of 2005 and 2015 is represented in Fig. 1. There were 3280 civilian deaths and 15,700 civilian injuries (NFPA, 2017a). There was a record $14.3 billion in property damages. This was the result of the 1,345,500 reported fires that occurred during this year (NFPA, 2017a). These numbers are astonishingly high, especially considering the United States is an industrialized nation that places strong emphasis on safety. It is also one of the most technologically advanced nations, which makes it even more surprising it ranks so high in fire death rates per million population. In 2007, the United States ranked 15th in fire death rates (FEMA, 2011). Switzerland, Singapore, Austria, and Italy were just a few of the countries which outranked the United States (FEMA, 2011). The United States had a death rate of 12.4, which was above the average of 10.7.

Noteworthily, structure fires have seen a decrease in recent years. Structure fire is defined as any fire in or on a building or other structure, even if the structure itself was not damaged (NFPA, 2017b). Vehicle fires, outside fires, and other fires, such as trash fire, are not included in this category. During this time frame, the largest number of structure fires occurred in 2007 with 530,500 fires (NFPA, 2017a). Afterwards, the total number of fires decrease immensely until 2012. Since 2013, structure fires have been on the rise again. With 2015 having the most structure fires since 2008. The high number of structure fires occurring indicates a problem with current suppression and prevention methods.

Both civilian injuries and fatalities have decreased slightly since 2005, Fig. 2. However, these numbers are still very high and unacceptable. The number of injuries from fire events centers around 16,000 annually. Some examples of injuries include burns (1st, 2nd, and 3rd degree), respiratory injuries etc. Respiratory injuries occur from not having enough oxygen in the air, inhalation of hot gases, and smoke inhalation. Civilian death totals are around 3000 per year. Most of these deaths are caused by smoke inhalation, not burns as the primary cause of the injuries. These elevated fatality and injury figures suggest that there is a major problem in this sector, though it is possible to decrease the number of fire injuries and deaths occurring through the introduction of innovative and creative solutions, such as the use of nanotechnology for fire prevention and protection.

Other effects of unwanted fire events include the damage costs to property and assets. Property damages were amounted to $14.3 billion in 2015 (NFPA, 2017a), Fig. 3. This was the highest it has been since 2008. Unfortunately, the trend for this data shows an increase in the past few years. If current methods of prevention and suppression are not improved upon or new solutions implemented, this cost could

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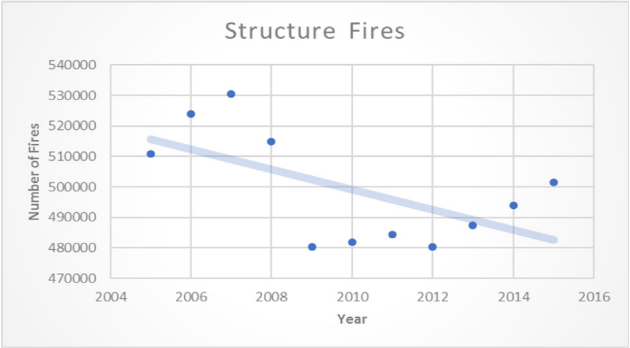

Fig. 1. Number of structural fires between 2005 and 2015 in the US (Courtesy NFPA, 2017a, 2017b)).

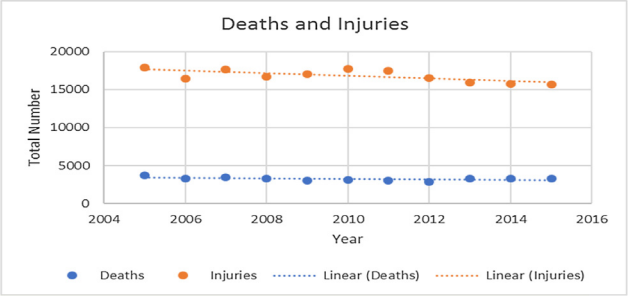

Fig. 2. Total number of injuries and fatalities from structure fire events from 2005 to 2015 (Courtesy NFPA, 2017a).

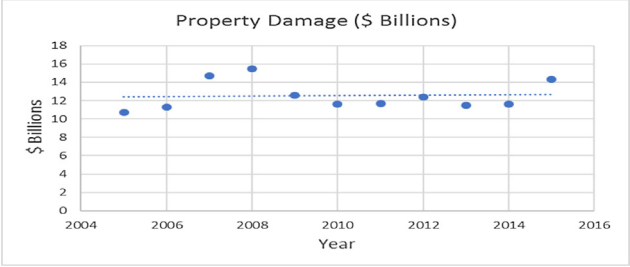

Fig. 3. Property damage costs from 2005 to 2015 due to fire (NFPA, 2017a).

continue to increase.

There are other aspects of the loss analysis that is also problematic. In 2010, property damage was $11.6 billion, this was only 3.5% of the total costs, the total cost of fire was $328 billion (NFPA, 2017a). These losses include human losses (i.e. deaths and medical treatment), economic costs (i.e. property loss and business interruption), and prevention/mitigation costs. Combined, these losses were about 2.2% of the United States GDP (NFPA, 2017a). The exceedingly high costs from the fire accidents is a huge concern however, the promising applications of nanotechnology for fire protection provides reasonable assurances that viable solution for the generational problem is possible.

1.1. Study aim statement

In today's world, there are always improvements made to new and existing things, e.g. structures, materials, methods and procedures. These improvements are intentionally designed to facilitate quality improvements to products and services, to the benefit of the consumers. Examples of such products may include but not limited to; cellular phones, cars, airplanes, home furniture and building materials.

Global economic growth driven by human population increase has lead to exponential increase in the demand of materials for human habitation. Building materials are made and produced as fast as they are being used, that is, all attempts are made to strike a balance between demand and available supply. These materials are made to be lighter, stronger and more durable. However, the problem with these materials can be their resistance to fires. Fire prevention and protection is a growing concern to the use of building materials in the construction industry as well as other industries. Building materials are also being made with materials and composites to improve their overall characteristics. The problem with this approach is that not all manufactures of these materials take into consideration their abilities to catch fire and burn in the event of a fire. The manufactures design includes making products to make the most profits, including using lighter, thinner materials, regardless of their flammability. With the use of nanotechnology, these manufacturers, and producers can make these products with the same lighter and thinner materials, while increasing their fire-retardant abilities (Holder et al., 2017).

Nanotechnology is the science, engineering, and technology conducted at the nanoscale, (which is about 1 to 100 nm) that enables the manipulation of materials to fit existing needs. Nanoscience and nanotechnology involve the ability to see and to control individual atoms and molecules. Everything on Earth is made up of atoms—the food we eat, the clothes we wear, the buildings and houses we live in, and our own bodies (US NNI, 2017). This impacts everything we do, not only in our everyday lives but also in these dangerous fire events. Nanotechnology can be used to create building materials and other coatings to provide a much safer polymeric material and other materials that are highly more resistant to fire and flame (Dong et al., 2014; Wang et al., 2017). Incorporating this technology into existing wood, clay, brick, mortar, cotton textiles, foams, paper, and cardboard along with many other materials, these materials are becoming more resistant to fires and creating safer buildings (Costes et al., 2017) and homes with a higher fire-resistant rating (FRR). Increased FRR's create a safer entrance to emergency workers in the event of a fire. Efforts are underway for the development of innovative solutions that include polymerized fire protection techniques that are innocuous to the environment, and the application of nanotechnologies integrated with polymer surface engineering for fire retardance (Malucelli et al., 2014).

2. Defining the applicability of nanotechnology in fire safety

Many of the solutions for building materials that are now effective against fire effects, started with the integration of nanotechnologies. These technologies drastically change the properties of the materials they are applied to and greatly increase their resistance to fire, fire retardancy, delayed char formations and create a safer environment when exposure to fire occurs. Using this technology can significantly increase fire prevention and protection strategies.

One innovative solution that must be explored is the use of nanotechnology in fire suppression systems such as: fire extinguishers and close loop suppression systems. The idea behind the use of nanotechnology in these systems would aim to provide a more universal and effective approach to putting fires out in all stages. Exploring different mixtures and chemical combinations with nanotechnology by breaking the materials down to particle size (10^{-9}) can help to strengthen the quality of the suppression mixture. This would increase the effectiveness and strength of its firefighting capabilities. Another use for this technology that must be explored further is its use in firefighting equipment and clothing. By using nanotechnology, the strength and durability of fibers in clothing and equipment can better resist fires and high thermal energy. This would help increase the safety for the firefighters while battling any stage of fire. Not only could this help firefighters fight fires in a safer manner, but it can also increase the safety of high risk workers. Some examples of these are people working around electrical hazards, steel workers, and welders.

Another area that could benefit from the use of nanotechnology is the automotive industry. There are many fires that break out in cars, whether it is from an accident or an overheating engine nanotechnology

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