Original Article

Risk Assessment of Nano-Flame Retardants Coating in the Selected Construction Industry of Iran by Control Banding Approach

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Abstract

Background: There is a wide range of challenges through the use of nano-material in buildings. By developing construction industries the use of flame retardant nano-materials is a hurdle for human health. However occupational exposure measurement is not applicable for nano-particles monitoring. Risk assessment is an alternative method for industrial hygiene strategies. In this study, we use the control banding approach for risk assessment of 3 nano-fire retardant (NFR) in the building industry. **Methods:** We used control banding as a risk assessment approach for decision making about nano-materials in the building industry. The risk of nano-fire retardants such as monokote accelerator, monokote Z-106 G and monokote Z-106 HY in the construction industry was studied. The level of risk was evaluated by the matrix of hazard severity and probability score. Hazard severity was scored by toxicological information. The probability score was estimated by the state work operation. **Results:** A score of hazard severity in monokot Z-106 HY was higher than other nano-materials. The probability score of spraying tasks was lower than mixing and transportation tasks. The results show the application of all nano-materials had the higher risk level in transportation and mixing tasks. The risk level of monokote accelerator and monokote Z-106 G in spraying task is lower than monokot Z-106 HY. **Conclusions:** There is a high risk level for studied nano-materials in the coating tasks of the construction industry. In conclusion, powerful controlling strategies such as the substitution of nano-materials was suggested to decrease the risk of nano-fire retardants.

Keywords: *Construction industry, control banding, flame retardant, nano-material*

Introduction

Growing of nano-material (NM) applications in industries increased the risk of nanoparticle in human health.[1,2] Unconventional and irregular properties of NM created challenges for governmental decisions. The traditional approach for risk assessment and keep the workers healthy is the use of occupational exposure limit. In this approach, sampling and analysis of airborne exposures are carried out and results are compared with the permissible limits of occupational exposure and then controlling processes are taken to reduce chemical exposure. But, increasing the number of dangerous NM is a hurdle for this approach.[3,4] In these years new strategies have been developed for risk assessment of chemicals in occupational exposure. Most nanoparticles have no occupational exposure limit in different international communities.[4] Moreover, there is no standard method for sampling of airborne NM. In this way characterize occupational exposure and NM toxicity by the use of standard protocols is difficult. A risk assessment of NM could be an efficient technique to consider the nano-material effect on human health.[5]

Control banding (CB) is a qualitative risk assessment and management strategy that involves a process of workplace risks based on a combination of hazard and exposure information. The utility of CB is recognized by a number of international organizations and it is a useful strategy for assessing and controlling occupational hazards.[6]

Control banding as control of substances hazardous to health model[7] is different strategies for chemical risk assessment. The control banding concept was firstly used in the pharmaceutical industry for making decisions in control processing.[8] Recently it was used as an effective technique for risk assessment of NM.[1]

Incomplete information about NM chemicals makes CB as an attractive

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approach for controlling nanoparticle exposures. It is an appropriate tool to assess the qualitative risk of NM.[9-11] Previous studies have reported that CB is a framework for qualitative risk assessment and managing occupational risks in the face of uncertainty.[12,13] Paik *et al*., introduced a pilot CB Nanotool for characterizing the health aspects of four operations and determine the level of risk and associated controls. They reported that CB Nanotool appears to be a useful approach for assessing the risk of nano-material operations and appropriate engineering controls.[4] Albuquerque *et al*. describe the use of a control banding tool to risk assessment of exposure of nanoparticles emitted during Metal Active Gas (MAG) arc welding. They explained that the CB tool is useful to evaluate the characteristics of arc welding procedures and protection measures could be derived, e.g., local ventilation devices, exhaust gas ventilation and containment measures.[14] Zalk *et al*. evaluated the CB Nanotool for structure, its weighting of risks and utility for exposure mitigation and suggested improvements for the CB Nanotool for the nanotechnology industries.[8] Aschberger *et al*. assessed the hazard data of different halogen-free flame retardants (FRs) in 5 industries and they reported that chemical alternatives assessment is an effective tool to find safer flame retardants.[15] U.S. Environmental Protection Agency (U.S. EPA) in a pilot study on engineered nano-materials developed the application of a web-based, interactive decision support tool and collected information about the risk potential of using multi-walled carbon nanotubes (MWCNTs) in flame-retardant coatings in upholstery textiles.[16,17]

NM was used in the construction industry widely.[18] Nanoparticles are used in the construction industry to reduce the weight and increase the stability of concrete, saving energy, improve crack resistance and corrosion and fire-retardant material.[19] Flame retardants are a wide group of chemicals used as the coating materials in buildings to delay the spread of fire.[20] Various types of nanoparticles such as SiO2,[21] carbon nanotubes (CNT) and metals,[15] and nano clay was applied as a fire retardant in different industries. Fire retardants create cell membrane and DNA/RNA damage while leads to direct oxidative stress.[22-24] These chemicals excited inflammatory response in lung tissue.[19] According to a lack of sufficient information about the occupational exposure limit of most nanomaterials and the health hazards of nano-fire retardants and their use in construction, it is important to conduct an appropriate risk assessment and determine exposure risks for these materials and taking appropriate control measures to reduce health risks of workers. Thus, occupational exposure to nano-fire retardants in construction is a point of attention in workers' health controlling.[25] Fire retardant nanoparticle is one of NM in this industry in which there are few studies on the risk exposure of Iranian workers to these materials in the construction industry. Because of this importance, in this study, we use the control banding approach for risk assessment of 3 nano-fire retardant (NFR) in the building industry.

Methods

In the present research three NFR entitled monokote accelerator, monokote Z-106 G and monokote Z-106 HY were studied. There is a mix of silica, aluminum sulfate, calcium sulfate, and hexavalent chromium in these components based on the material safety data sheet (MSDS) of these fire retardants.[13,26,27] Flame retardants coating on the surfaces have been operated in 3 steps. Thus NFR risks were evaluated in 3 tasks of transportation, mixing and spraying. The statistical population of this study was 18 male workers working in construction company that the studied subjects included 3 person transport of nano-materials, 10 person discharging materials in the blender, and mixing of nano-materials with water and 5 people spraying material by the nozzle on the surfaces.

We calculated risk level by control banding method based on the procedure suggested by Paik.[4] In summary, risk level depends on the hazard and probability of exposure. The severity of exposure was determined according to particle size, shape, solubility, and toxicity [Table 1].[4,28]

Probability of exposure was assigned by operation in dry (dustiness) or wet (mistiness) processing, the number of exposed subjects, frequency, and duration of exposure [Table 2].[4,28]

After calculating the score of each of the sub-factors, the sum of scores for the part of exposure severity was in one of the following ranges:

Low: 0-25 Medium: 26-50 High: 51-75 Very high: 76-100

Moreover, for probability, the classification was as follows:

Extremely unlikely: 0-25 Less likely: 26-50 Likely: 51-75 Probable: 76-100

Score severity and probability was identified in four levels and then the risk level was calculated based on a 4*4 matrix and the risk level was determined so that the level of risk RL1 was given in green, the risk level of RL2 was given in yellow, the risk level of RL3 was given in orange and the risk level of RL4 was given in red [Table 3].[4]

The control measures for each risk level are as follows:

RL1: General ventilation

RL2: Fume hoods or local exhaust ventilation

RL3: Enclose the process or containment

RL4: Seek specialist advice[4]

The aforementioned scores were completed using raw forms and tables for each of the 3 activities and analyzed and classified using the control banding

Table 1: Hazard severity calculation[4,28]

Factors	Descriptors=score				
Hazard severity of parent material					
Toxicity OEL	<10 μg/m³=10	10-100 μg/m³=5	101 μg/m³ to 1 mg/m³=2.5	>1 mg/m³=0	Unknown=7.5
Carcinogenicity	Yes=4	No=0	Unknown=3		
Reproductive toxicity	Yes=4	No=0	Unknown=3		
Mutagenicity	Yes=4	No=0	Unknown=3		
Dermal hazard	Yes=4	No=0	Unknown=3		
Asthmagen potential	Yes=4	No=0	Unknown=3		
Hazard severity of nanomaterial					
Surface chemistry	High surface reactivity=10	Medium surface reactivity=5	Low surface reactivity=0	Unknown=7.5	
Particle shape	Tubular or fibrous=10	Anisotropic=5	Compact or spherical=0	Unknown=7.5	
Particle diameter	1-10 nm=10	11-40 nm=5	41-100 nm=0	Unknown=7.5	
Solubility	Insoluble=10	Soluble=5	Unknown=7.5		
Carcinogenicity	Yes=6	No=0	Unknown=4.5		
Reproductive toxicity	Yes=6	No=0	Unknown=4.5		
Mutagenicity	Yes=6	No=0	Unknown=4.5		
Dermal toxicity	Yes=6	No=0	Unknown=4.5		
Asthmagen	Yes=6	No=0	Unknown=4.5		

Table 2: Exposure probability calculation[4,28]

Factors	Descriptors=score				
Exposure probability					
Dustiness/mistiness	High=30	Medium=15	Low=7.5	None=0	Unknown=22.5
Estimated amount of nanomaterial used during task	0-10 mg=6.25	11-100 mg=12.5	>100 mg=25	Unknown=18.75	
Number of employees with similar exposure	1-5 employees=0	6-10 employees=5	11-15 employees=10	>15 employees=15	Unknown=11.25
Frequency of operation	Daily=15	Weekly=10	Monthly=5	<monthly=0	Unknown=11.25
Duration of operation	<30 min=0	30-60 min=5	1-4 h=10	>4 h=15	Unknown=11.25

Table 3: Risk level (RL) matrix as a function of severity and probability[4]

	Exposure probability			
	Extremely unlikely (0-25)	Less likely (26-50)	Likely (51-75)	Probable (76-100)
Hazard severity				
Very high (76-100)	RL 3	RL 3	RL 4	RL 4
High (51-75)	RL 2	RL 2	RL 3	RL 4
Medium (26-50)	RL 1	RL 1	RL 2	RL 3
Low (0-25)	RL 1	RL 1	RL 1	RL 2

tools program version 2-6-18-09.[28] In order to collect information about the severity-related factors, the material safety data sheet was used, and the workers' observations and interviews with the company's supervisor were used to collect information about probability factors.

Results

Properties of NM in the studied tasks have been shown in Table 4. According to the table, the component for the Monokot Accelerator is Aluminum Sulfate. Also, components for the Monokot Z-106 G are included SiO2 and Calcium Sulfate and for Monokot Z-106 HY contains four components of SiO2, Calcium Sulfate, Portland cement, and Hexavalent Chromium. All 3 nano-fire retardants were used in transportation, mixing and spraying, tasks, and workers used personal protective equipment (PPE) at work.

Different parameters of hazard severity for NM was evaluated according to toxicity information. The results show the hazard severity score in the solubility parameters was higher level for 3 NMs. Particle size in studied materials has a lower level of hazard severity score [Table 5].

The severity score was calculated by adding severity parameters in different NMs. According to the total score of the sub-factors, the severity was 68.5 and 60.5 for

Table 4: NM in the studied tasks

NM	Composition	Tasks	Used Engineering Control
Monokot Accelator	Aluminium sulphate	Transportation, Mixing, Spraying	Personal protective equipment
Monokot Z-106 G	SiO_2, Calcium Sulfate		
Monokot Z-106 HY	SiO_2, Calcium Sulfate, Portland cement, Hexavalent Chromium		

Table 5: Hazard severity score in studied NM based on the CB method

Hazard Severity	Factors	Monokot accelator		Monokot Z-106G		Monokot Z-106 HY	
		Reported parameter	Score	Reported parameter	Score	Reported parameter	Score
Parent material	OEL (mg/m^3)	1	2.5	0.025	2.5	0.025	2.5
	Carcinogenicity	No	0	Yes	4	Yes	4
	Reproductive toxicity	No	0	No	0	Yes	4
	Mutagenicity	No	0	Unknown	3	Yes	4
	Dermal hazard	No	0	Yes	4	Yes	4
	Asthmagen potential	Unknown	3	Yes	4	Yes	4
Hazard severity of NM	Surface reactivity	Unknown	7.5	High	10	High	10
	Particle shape	Unknown	7.5	Unknown	7.5	Unknown	7.5
	Particle diameter	100	0	100	0	100	0
	Solubility	Insoluble	10	Insoluble	10	Insoluble	10
	Carcinogenicity	Unknown	4.5	Yes	6	Yes	6
	Reproductive toxicity	Unknown	4.5	Unknown	4.5	Unknown	4.5
	Mutagenicity	Unknown	4.5	Unknown	4.5	Unknown	4.5
	Dermal toxicity	Unknown	4.5	Unknown	4.5	Yes	6
	Asthmagen	Unknown	4.5	Unknown	4.5	Yes	6

Z-106G and accelator, respectively, and 84.5 for the Z-106 HY material. The results show the hazard severity score for monokot Z-106 HY is a higher level than others with a very high severity score band [Table 6].

All of the studied NM was used in transportation, mixing and spraying tasks. Table 7 presented the probability score of NMs in different tasks. The results show probability score in mixing and transportation tasks is higher than spraying task due to dry processing.

Probability bands for NMs using in spraying, mixing, and transportation was shown in Table 8. Based on the results, the score of probability factor in transportation for all three types of nanomaterial was 77.5 and at the "probable level", in the mixing was 82.5 and the "probable level" and in the activity related to spraying materials on these surfaces was 55 and "likely level". The results show probability bands for mixing and transportation are equal and are higher than the spraying task.

Based on the hazard and probability score, the risk level (RL) of NMs was estimated. The results show RL of monokot accelerator, monocot Z-106 G and monokot Z-106 HY is 4 and the red color state for transportation and mixing tasks. The risk level in the spraying task was presented in Table 9. Therefore, it is necessary to use the containment control action for the risk level of RL3 and seek specialist advice at the risk levels of RL4.

Table 6: Hazard severity bands in studied NM based on the CB method

NM	Monokot Z-106G	Monokot accelator	Monokot Z-106 HY
Hazard Severity score	68.5	60.5	84.5
Hazard Severity band	High	High	Very high

Table 7: Probability score in different tasks based on the CB method

Factors	Probability Score		
	Transportation	Mixing	Spraying
Dustiness/mistiness	30	30	7.5
Estimated amount of nanomaterial used during task	25	25	25
Number of employees with similar exposure	0	5	0
Frequency of operation	11.25	11.25	11.25
Duration of operation	11.25	11.25	11.25

Discussion

Construction occupations are one of the industries deals with different risk factors, such as injuries and diseases. Although various efficient solutions have been identified application of nano-materials in the building industry is a health risk yet.[29] Control banding is used to supplement existing OELs so that the health of employees who work with chemicals lacking an OEL (for example NM) is protected. Also, it is

Table 8: Probability bands in studied NM based on the CB method

Task	Transportation	Mixing	Spraying
Probability score	77.5	82.5	55
Probability bands	Probable	Probable	Likely

Table 9: The risk level of NM in the spraying task

Task	Risk level
Monokot Z-106 HY	4
Monokot accelator	3
Monocot Z-106 G	3

a simplified approach that uses qualitative risk evaluation methods in order to evaluate the risks of NM.[30]

Therefore, it is considered to be an efficient risk assessment method for the construction industry. Fire retardant nanoparticle is one of NM in this industry, which limited studies evaluate the risk of them. In the present study, control banding Nanotool was used for the qualitative risk evaluation of fire retardants in coatings task of building industry in Iran. Hazardous materials such as silica and chromium VI were found in fire retardants. SiO2 and chromium IV were classified as human carcinogenic materials.[31,32] Moreover, chromium IV is a mutagenic matter[33] causing asthma and contact dermatitis; it also causes reproductive toxicity in exposed workers.[34] The high hazard score of CB confirmed this toxicity due to the presence of silica in Monokot Z-106G and silica and chromium IV in Monokot Z106 HY. However, the hazard score of Monokot Z106 HY is higher than Monokot Z-106G based on the reproductive and dermal toxicity as the same as its asthmagen property. The frequency and duration of exposure to nano-material using were equal in transportation, mixing and spraying tasks. In the spraying task, workers were operated by wet processing. Moreover, the number of employees in the shooting of coating was lower than other tasks. These reasons lead the probability score of sparing tasks to lower levels than others.

There are four risk levels based on the control banding tool[4] while the risk of 4 value presented at the highest risk level. Our study showed the use of Monokot Z-106G, Monokot Accelerator, and Monokot Z106 HY has the highest risk level in transportation and mixing tasks while theses application requests specific advice and maximum controlling the action. Also for sprayer workers, the use of Monokot Z106 HY needs specific advice while the risk level of Monokot Z-106G and Monokot Accelerator demand containment proceeding. Jonkers *et al*. reported a comparison between the overall environmental impact of Brominated flame retardants and Halogen-free flame retardants in a laptop by Life Cycle Assessment (LCA). The result showed the Brominated flame retardants has a higher impact and the substitution of Brominated flame retardants by Halogen-free flame retardants is beneficial in clear environmental.[35] In another study, Huang performed a human health risk assessment for one of the brominated flame retardants named Bis (2-ethyl-1hexyl) tetrabromophthalate (BEH-TEBP) based on available scientific literature and they have been calculated the Risk Characterization Ratio (RCR). The result showed that the Risk Characterization Ratio was calculated based on the DNEL of 0.37 mg/kg bw/day (ECHA 2016b) for oral exposure.[36] In conclusion, the risk of studied NFR in coating tasks of the building industry is at the highest level and the use of local exhaust ventilation is not sufficient for risk control. Based on this study, powerful controlling managing such as the substitution of NM was suggested. It is important that control banding strategy is not a replacement for traditional exposure monitoring and experts in occupational health and safety nor does it eliminate the need to take air samples and use of OEL. CB highly recommends seeking professional assistance and exposure monitoring to follow the CB intervention to ensure the installed controls are working properly.[6,37]

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Conflicts of interest

There are no conflicts of interest.

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