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Occupational safety risk assessment in magnesite thermal processing: a case study of shaft furnace operations

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Abstract:

This case study analyses occupational safety risks associated with two selected occupations – machine operator and furnace operator – in the shaft-furnace section of a magnesite thermal processing plant. The work environment includes hazards related to process equipment, thermal load, dust, noise, mechanical factors, and human and organisational factors. The aim is to identify and evaluate the risk level for the two occupations and to formulate risk-reduction measures.

The Comprehensive Method was applied, taking into account machinery and process equipment, the working environment, and personnel. The calculated risk values were $R = 19.584$ for the machine operator and $R = 24.95$ for the furnace operator, both exceeding the applied acceptability threshold of $R < 10$.

Keywords:

Safety, occupational risk assessment, comprehensive risk assessment, shaft furnace.

1. Introduction

Plants for the thermal processing of minerals are working environments in which several factors may adversely affect the safety and health of employees. The nature of the production processes, high working temperatures, movement of process equipment, handling of raw and processed materials, dust, noise, vibrations, chemical substances, and other physical, chemical, and mechanical factors create complex working conditions in which various occupational risks may arise (Samchuk-Khabarova et al., 2019; Rozenfeld et al., 2010).

Safety in such operations is therefore significantly influenced not only by the technical condition of the equipment and the level of the production processes, but also by the nature of individual work activities and the conditions under which employees perform their work. For this reason, hazard identification and subsequent safety risk assessment are essential components of an occupational health and safety management system (Sánchez et al., 2017; Sousa et al., 2014).

The article presents a case study of occupational safety risks associated with two selected occupations in the shaft-furnace section of a magnesite thermal processing plant.



Attention is focused on hazards connected with work activities, process equipment, the working environment, and work organisation. The aim is to assess the risk level associated with the machine-operator and furnace-operator positions and to identify priorities for preventive measures (Kaassis and Badri, 2018; Aneziris et al., 2012).

The Comprehensive Method is applied in the main part of the paper. The method combines parameters representing machinery and process equipment, the working environment, and personnel. Contemporary occupational-safety research emphasises that risk assessment should integrate technical, environmental, organisational, and human factors and should be followed by verification of the effectiveness of controls (Kirin et al., 2021; Liu et al., 2023; Pinto et al., 2011).

The study therefore focuses on a defined industrial case rather than on mineral processing as a whole. Its practical contribution is the structured comparison of two occupations exposed to different combinations of thermal, mechanical, environmental, and human-factor hazards, while its limitations are addressed in the discussion.

2. Material and methods

2.1 Study area

The magnesite plant in Jelšava (Fig. 1) is the largest magnesite mining and processing plant in Slovakia. On a global scale, it is also one of the major producers of dead-burned magnesia (DBM). The plant is currently part of Slovenské magnezitové závody, a.s., Jelšava. Its history dates back more than 120 years. Throughout its existence, the plant has undergone several organisational and technological changes. The Jelšava state enterprise was established on 1 January 1993 following the division of the SMZ Košice state enterprise. Subsequently, on 16 February 1994, it was transformed into a joint-stock company through registration in the Commercial Register (Internal materials – SMZ, a.s. Jelšava).

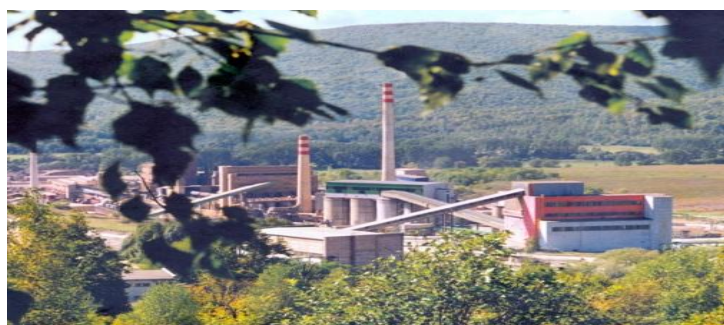


Fig. 1 Magnesite plant in Jelšava (SMZ, a.s. Jelšava)

Magnesite ore is extracted by underground mining methods from the plant's own Dúbravský Massif deposit. This deposit is considered one of the most significant magnesite deposits worldwide due to the extent of its geologically verified and accessible reserves, its mine development system, as well as its geological and mining conditions. The extent of the recorded magnesite reserves provides the potential for continued extraction and processing of the raw material for several decades. Mining is carried out using an advanced, environmentally friendly room-and-pillar method with backfilling of the mined-out areas. Modern trackless mining equipment, particularly drilling and haulage machinery, is used in the extraction process (Internal materials – SMZ, a.s. Jelšava).

The main products obtained from the processing of magnesite ore include bulk dead-burned magnesite refractory products, caustic magnesia, and slag-forming additives. These

products are used primarily in the steel industry, refractory production, the chemical industry, agriculture, and construction (Internal materials – SMZ, a.s. Jelšava).

2.2 Thermal unit for magnesite processing: the shaft furnace

Shaft furnaces (Fig. 2) are among the oldest and most important process units used in various industrial sectors. Their use dates back to the 19th century. In the past, shaft furnaces were mainly constructed from stone blocks and were among the primary units used for ore processing and metal production. Today, they are used for the processing of ores and concentrates, pellet firing, the production of building materials, and other production processes. Depending on their purpose and the nature of the production process, shaft furnaces can be classified as melting, roasting, firing, heating, gasification, distillation, and other types. This indicates that various physical and physicochemical processes can take place in shaft furnaces (Internal materials – SMZ, a.s. Jelšava).

Shaft furnaces are characterised by a vertically arranged working space with a predominantly circular horizontal cross-section. This design allows for a more uniform distribution of the charge and contributes to reducing heat losses. The main part of the furnace is the shaft, into which granular charge material, process additives, and fuel required to provide heat are introduced (Internal materials – SMZ, a.s. Jelšava).



Fig. 2 *Shaft furnaces at SMZ, a.s. Jelšava*

As the charge gradually moves downwards through the shaft, individual processes and reactions take place, resulting in changes in the properties of the processed material. The processed material is subsequently discharged from the lower part of the furnace. Fuel and combustion air are introduced into the lower or middle section of the shaft furnace. The combustion gases and other gases generated during the production process flow countercurrently to the descending charge and are subsequently discharged from the upper part of the furnace. The main function of the combustion system is to provide the heat required for the production processes. Gaseous fuels are predominantly used in shaft furnaces (Internal materials – SMZ, a.s. Jelšava).

2.3 Safety assessment methods

In simplified terms, occupational safety can be defined as a set of measures aimed at preventing harm to health and reducing risks associated with work activities. A work process can be considered safe when it is carried out under specified conditions and in compliance with the relevant safety requirements. These include, in particular, compliance with legal and internal regulations, safety rules and instructions, production and work procedures, as well as instructions for the operation and maintenance of equipment. Safe working conditions also

require the minimisation of unexpected external influences, thereby reducing the possibility of endangering the life and health of persons, causing material damage, or damaging the environment. The following methods are used for risk analysis:

- A safety audit (SA) is one of the oldest methods for identifying and assessing risks. It typically consists of a series of inspection rounds, which may be conducted over an extended period and during which selected production facilities, workplaces, process equipment, or their components are systematically and objectively assessed. The aim of a safety audit is to identify deficiencies in terms of occupational safety and to assess compliance with established safety requirements.
- The Comprehensive Method represents a simple and systematic approach to risk assessment, particularly suitable for small and medium-sized enterprises. It enables workers to assess the level of risk of occupational injury based on several factors affecting the workplace. The method is based on the assumption that occupational risk generally results from multiple causes and the interaction of various factors. The assessment primarily considers three basic areas: the influence of machinery and process equipment, the influence of the working environment, and the influence of the human factor (Holizki et al., 2015; Meyssonnier and Zawadzki, 2008).

2.4 Occupations involved in shaft-furnace heat treatment

In the thermal processing of raw materials in shaft furnaces, the following occupations are involved at individual stages of the production process, performing activities from the entry of raw materials into the thermal processing stage through to the discharge of the processed material:

- Machine operator
- Furnace operator (Internal materials – SMZ, a.s. Jelšava).

The machine operator is responsible for operating and monitoring machinery and process equipment throughout the individual stages of the production process. Their duties include starting, operating, shutting down, cleaning, and adjusting machinery and process equipment, as well as monitoring the correctness of process parameters and operational safety. The job also includes ensuring the loading and transportation of gravel, sand, raw materials, and other materials using designated equipment and means of transport, performing material handling activities, and checking the proper use of materials and additives. The machine operator is also responsible for maintaining the required quality of the production process and complying with occupational health and safety principles. They also carry out regular inspections of machinery, the workplace, and protective and safety devices to ensure that they function properly. The operation of belt conveyors is also part of the machine operator's duties (Internal materials – SMZ, a.s. Jelšava).

The furnace operator in the shaft-furnace section is responsible for ensuring the continuous and safe operation of the furnace line and contributes to maintaining the required quality of the production process and manufactured products. Their duties primarily include ensuring the operational readiness of the furnace line, achieving the required furnace output in accordance with technical and economic standards, and implementing measures to reduce secondary dust emissions. The furnace operator ensures the firing of clinker to the required quality and monitors the operational condition of individual components of the furnace line. They are responsible for the proper operation of the dust removal system and ensure a continuous supply of raw material to the individual thermal units, as well as the removal of fired material from the furnaces. The furnace operator also checks the condition of protective and safety devices and performs visual inspections of the quality of the clinker produced. They are responsible for product quality, take samples from the furnaces, and, when

necessary, eliminate operational deficiencies and equipment faults. An important part of the work involves ensuring proper burner combustion in the shaft furnaces and regularly charging raw material into the furnaces. The furnace operator also performs regular lubrication of machinery and complies with the relevant safety and operating regulations when working with gas equipment. They monitor the proper combustion of natural gas, supervise the operation of individual machines and process equipment, and continuously assess working environment conditions. They also perform the necessary material handling activities and check the functionality of control elements. During all work activities, the furnace operator is required to comply with established production procedures, operating and safety regulations, as well as occupational health and safety principles (Internal materials – SMZ, a.s. Jelšava).

3. Results and discussion

To assess safety risks comprehensively in a mineral thermal processing plant, selected occupations involved in the individual production processes were analysed. The assessment focused on risks arising from the nature of the work performed, the machinery and process equipment used, the working environment, as well as factors related to the employee and the organisation of work.

The Comprehensive Method was used to determine the level of safety risk associated with individual occupations. This method enables the assessment of risk based on three basic areas, namely the influence of machinery and process equipment, the influence of the working environment, and the influence of personnel. The individual areas are expressed by the parameters S, E, and O.

Parameter S (Fig. 3), the influence of machinery and process equipment, considers the nature of hazards associated with the machinery and equipment used. Within this parameter, particular attention was paid to the potential damage and its consequences (D), exposure to hazards in terms of frequency and duration (E_x), the probability of an accident or occupational injury caused by machinery (p), and the possibility of preventing or minimising the resulting damage (M). The method and criteria used to assess the individual indicators are presented in Tab. 1.

Severity D	Description of the criterion	Examples	Graphical representation
1 (minor consequences)	Injuries with minor consequences (bruises, sprains, minor cuts), equipment damage, and operational disturbances (near-miss events).	• minor injuries • temporary incapacity for work up to 3 days • minor equipment damage	
5 (serious consequences)	Hazardous injuries with serious consequences (fractures, deep cuts), injuries to multiple persons.	• serious injuries • long-term incapacity for work • more extensive equipment damage	
10 (severe consequences / fatal injury)	Hazardous injuries with permanent consequences, mass injuries, or fatal injuries.	• permanent health consequences • fatal injury • extensive equipment damage	

Fig. 3 *Parameter S – Influence of Machinery and Process Equipment*

Parameter E (Fig. 4), the influence of the working environment, expresses the level of risk associated with the conditions under which the work activity is performed. Its determination takes into account, in particular, the layout of the workplace and intervention zones (U), the characteristics of the working environment (P_p), and other work-related loads (Z). The assessment criteria for these factors are presented in Tab. 2.

Value E	Description of the criterion	Examples	Graphical representation
0.3 (favourable conditions)	Working environment with minimal adverse factors.	- adequate lighting - acceptable noise level - favourable temperature, dust and humidity	
0.5 (moderate conditions)	Working environment with noticeable adverse factors.	- increased noise level - higher dust concentration - elevated or lower temperature	
0.6 (adverse conditions)	Working environment with significant adverse factors.	- high noise level - high dust concentration - high temperature or humidity - insufficient lighting	

Fig. 4 *Parameter E – Influence of the Working Environment*

Parameter O (Fig. 5), the influence of personnel, takes into account factors related to the employee and the organisation of their work activities. Within this parameter, the employee's qualification (Q), physical and psychological factors (Φ), and work organisation (O_p) were assessed. The individual criteria and values used in the assessment are presented in Tab. 3.

Value O	Description of the criterion	Examples	Graphical representation
10 (favourable conditions)	Qualified and trained person with experience.	- appropriate professional qualification - completed training - sufficient practical experience	
5 (moderate conditions)	Qualified and trained person with limited experience.	- professional qualification - training provided - limited practical experience	
0 (adverse conditions)	Unqualified or untrained person without experience.	- no professional qualification - no training - no practical experience	

Fig. 5 *Parameter O – Influence of Personnel*

Once the values of the individual sub-indicators had been established, the resulting values of parameters S, E, and O were calculated for each occupation assessed. These values were subsequently substituted into the equation for determining the risk acceptability level:

$$R = S \times E - O \times (S/30) \quad (1)$$

where: S – influence of machinery,

E – influence of the working environment,

O – influence of personnel.

The resulting value R represents the level of risk associated with a specific occupation and enables its classification into the corresponding risk acceptability level. Based on the calculated values, the individual occupations could be compared in terms of their safety risk levels, and occupations with an increased level of hazard could be identified.

The assessment results (Fig. 6) also make it possible to identify the main factors contributing to the resulting level of risk. Particular attention should therefore be paid to occupations performed in the immediate vicinity of thermal units, process equipment, and areas characterised by elevated temperatures, dust, noise, mechanical hazards, or other adverse working conditions. The results obtained provide a basis for establishing priorities when implementing preventive and protective measures for individual work activities.



Fig. 6 Risk Acceptability Level

3.1 Assessment of occupational safety risks – Comprehensive method

This subsection focuses on the assessment of safety risks associated with individual occupations. The assessment takes into account the influence of machinery and process equipment (Tab. 1), the working environment (Tab. 2), and the human factor (Tab. 3). Based on the values obtained, the resulting risk level and the corresponding risk acceptability level are determined for each occupation (Tab. 4).

Tab. 1 Calculation of parameter S (Influence of machinery)

Parameter S – influence of machinery	Assessment scale	Determined value – machine operator	Determined value – furnace operator
Consequences	1 – 10	9	10
Exposure (frequency and duration)	1 – 2	1.7	1.9
Probability of injury	0.5 – 1.5	1.2	1.3
Possibility of damage	0.5 – 1	0.8	0.9
Minimisation			
Calculation ($S = D \times E_x \times p \times M$)		14.688	20.23

Tab. 2 Calculation of parameter E (Influence of the working environment)

Parameter E – influence of the working environment	Assessment scale	Determined value – machine operator	Determined value – furnace operator
Workplace layout	0.5 – 1	1	1
Working environment	0.3 – 0.6	0.5	0.5
Other work-related loads	0.2 – 0.4	0.3	0.3
Calculation ($E = U + P_p + Z$)		1.8	1.8

Tab. 3 Calculation of Parameter O (Influence of Personnel)

Parameter O – influence of personnel	Assessment scale	Determined value – machine operator	Determined value – furnace operator
Employee qualification	0 – 10	8	10
Physical and psychological factors	0 – 3	2	3
Work organisation	0 – 5	4	4
Calculation ($O = Q + \Phi + O_p$)		14	17

The risk assessment conducted using the Comprehensive Method showed that the resulting risk value exceeded 10 ($R > 10$) for both assessed occupations, which represents an unacceptable level of risk. Therefore, appropriate preventive and protective measures need to be proposed and implemented to reduce the identified risks (Tab. 4).

The higher risk calculated for the furnace operator ($R = 24.95$) compared with the machine operator ($R = 19.584$) is driven mainly by parameter S: 20.23 vs 14.688. The working-environment parameter E is identical for both occupations (1.8), while the personnel parameter O is higher for the furnace operator (17 vs 14). Within parameter S, the furnace operator received higher ratings for consequences (10 vs 9), exposure (1.9 vs 1.7), probability of injury (1.3 vs 1.2), and possibility of damage minimisation (0.9 vs 0.8). Thus, the difference in the final R values originates primarily from the assessment of machinery- and process-related hazards rather than from the working-environment score.

Tab. 4 Resulting risk and risk acceptability level

Resulting risk value for occupations	Determined value – machine operator	Determined value – furnace operator
Parameter S	14.688	20.23
Parameter E	1.8	1.8
Parameter O	14	17
Calculation		
($R = S \times E - O \times (S/30)$)	19.584	24.95
Risk Acceptable?	No	No

3.2 Proposed technical and organisational measures

As part of the safety risk assessment, a set of technical and organisational measures was proposed, the implementation of which could significantly reduce the level of safety risks associated with the assessed occupations. The proposed measures are primarily aimed at eliminating or minimising sources of hazards, limiting employees' exposure to risk factors, and ensuring the safe operation of process equipment. The proposed measures include:

- preventive elimination or reduction of potential hazards during operation,
- reduction of the exposure time of selected occupations to risk factors,
- strict use of personal protective equipment (PPE) in accordance with the relevant requirements and internal regulations, particularly protective helmets, helmet liners, hearing protection, dust respirators, protective gloves, safety goggles, protective clothing, special protective clothing, safety footwear, and special protective footwear,
- carrying out repairs, maintenance, and handling of equipment exclusively when the equipment is safely shut down and secured against being started,
- restricting employee movement to safe areas designated for operating personnel,
- preventive elimination and minimisation of the risk of objects falling or being released,
- removal of obstacles from walkways that may cause employees to trip or stumble,
- strict compliance with the prohibition on removing or bypassing protective barriers and guards of process equipment,
- prohibiting unauthorised persons from entering hazardous areas, and ensuring the stability of process equipment,
- operation of process equipment exclusively with functional protective guards that prevent access to hazardous areas,

- maintaining electrical equipment in a safe technical condition and ensuring regular inspection by suitably qualified persons,
- preventing unauthorised interventions in electrical installations and ensuring protection against dangerous contact with or approach to live parts of electrical equipment,
- equipping each conveyor belt at its beginning and end with an emergency stop switch; for exposed conveyor belts, an emergency pull cord with limit switches at both ends should be provided along the entire length on the operator's side, and the functionality of the emergency shutdown system should be checked regularly,
- ensuring effective collective protection of employees against risks associated with exposure to biological, chemical, and other harmful factors in the working environment,
- appropriate placement of fire extinguishers and firefighting equipment in the vicinity of equipment where there is a risk of fire,
- regular removal of obstructions and unnecessary objects from floors and walkways of process lines in order to prevent employees from tripping, stumbling, or falling,
- prohibition of approaching or remaining in the vicinity of operating process equipment unless necessary for the performance of work activities,
- ensuring that minimum workplace lighting requirements appropriate to the nature of the work are met,
- thorough cleaning, inspection, and regular maintenance of process equipment in order to identify technical faults at an early stage and eliminate the associated safety risks.

4. Conclusions

This study assessed occupational safety risks associated with the machine-operator and furnace-operator positions in the thermal processing of magnesite using shaft furnaces. The risk values calculated using the Comprehensive Method were $R = 19.584$ for the machine operator and $R = 24.95$ for the furnace operator, both exceeding the applied acceptability threshold of $R = 10$.

The assessment showed that the furnace-operator position was associated with a higher level of occupational risk, primarily due to the higher value of parameter S , which represents the influence of machinery and process equipment. The results also confirmed the importance of considering the combined effects of machinery, the working environment, and human factors when assessing occupational risks in thermal processing operations.

Based on the identified hazards and the results of the risk assessment, a set of technical, organisational, and preventive measures was proposed to reduce the identified risks. These measures include safe shutdown and securing of equipment during maintenance, functional protective guards and emergency-stop systems, measures to reduce exposure to dust, noise, and elevated temperatures, restricted access to hazardous areas, regular inspection and maintenance of process equipment, appropriate workplace organisation and housekeeping, employee training, and the consistent use of appropriate personal protective equipment.

The implementation of the proposed measures should contribute to reducing employees' exposure to identified hazards and consequently to decreasing the level of occupational risk. Particular attention should be paid to hazards associated with machinery and process equipment, as these factors contributed substantially to the calculated risk values, especially for furnace operators.

The results demonstrate the practical applicability of systematic occupational risk assessment for identifying critical factors and establishing priorities for preventive measures

in mineral thermal processing operations. The Comprehensive Method provides a structured approach for evaluating the influence of machinery and process equipment, the working environment, and personnel, thereby supporting the selection of appropriate measures for improving workplace safety.

Systematic assessment of occupational safety risks, followed by the implementation of appropriate technical, organisational, and preventive measures and regular verification of their effectiveness, can contribute to reducing the probability of occupational accidents and improving occupational health and safety in mineral thermal processing operations.

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