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EVALUATION OF THE OCCUPATIONAL RISK ASSOCIATED TO WORK ENVIRONMENT IN FERROUS METALLURGY

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ABSTRACT

Work environment present risk factors due to chemical pollution of ambient air with dust, smoke, fumes, vapors, mists and gases. Moreover physical risk factors (related to noise, lighting, temperature, vibration, humidity, radiation) lead to hazards with varying degrees of significance. In this paper were identified the hazards associated with the work place for a maintenance worker who works in all sectors of metallurgical plant. The risk assessment was made in terms of severity and probability, combining these two factors in a risk matrix. From the analysis the significant hazards (unacceptable) related to work environment resulted. These are caused by the presence of the following pollutants: toxic gases (VOCs, PAHs, dioxins, furans), explosive flammable gases (methane gas, blast furnace gas, bigaz, oxygen), carbon monoxide and particulate matter.

KEYWORDS: risk factors, hazards, work environment, integrated steel plant

1. Introduction

The work environment presents the following important risk factors: chemical factors (dusts, gases, vapours, mists, fumes etc.); physical factors (noise, vibrations, radiation, excessive humidity, lighting etc.); thermal factors (high or low temperatures, abrupt changes of temperature). The raw materials, the energy sources, the technologies and the processes in ferrous metallurgy sector lead to a work environment with significant risk [1, 2]. This paper proposes to identify the factors of occupational risk and the hazards which they may generate. It also proposes to assess which of the risks are major through the significantly consequences on the workers health from steelmaking plant and what measures may apply for their minimization. All judgments shall relate to work environment and they do not deal with other risk factors that can be taken into account for assessment of a workplace and that are related to means of production, work obligations, execution of operations etc.

Firstly, work environment in ferrous metallurgy presents the risk of air pollution with: dust particles (coarse, fine and very fine), smoke, steam, vapours, mists and gases (CO, CO_2, SO_2, NO_x, H_2S, NH_3, VOC_s, CH_4) [3]. Also there are present the physical risk factors such as noise (continuous, intermittent, impulse), lighting (excessive, shine, incorrect, inappropriate), temperature (heat or extreme cold, heat shocks), vibrations, humidity, radiations. The hazards are principally related to the fugitive emissions (diffuse) and less to the controlled emissions. Fugitive emissions may be continuous andare produced mainly by imperfect seals (loading systems, conveying lines, furnaces doors, manholes, refractory lining etc.) or uncontinuous (loading and unloading, maintenance of facilities, damages, accidents and others) [4].

2. Risks related to the work environment in ferrous metallurgy

Environmental pollutants that impact upon work security are different (in terms of amount and type of pollutant) or common to steel plants. For example, the dust and VOCs appear on all metallurgical flow, while the ammonia is present only in coke production sector. Significant quantities of particulate matter are to be found in the sectors of raw materials, of coke production and sinter and less in the other sectors. From a certain level of pollution or by storage in the body, most environmental pollutants from steel work can cause diseases.

The most common work-related ailments in ferrous metallurgy and their causes are shown in Table 1. The routes of exposure are the inhalation, skin absorption (or percutaneous absorption) and ingestion [5-10].

Table 1. *Diseases associated with work environment and with risk factors that produce them*

Diseases associated with profession	Potential risk factors
Respiratory ailments	Low temperatures, air courses, air polluted with dust, toxic and irritant gases, smoke, fly-ash, vapours, nickel and manganese.
Ischemic heart disease	Noise, vibrations, high temperatures, heat radiations
Nervous system diseases and neuropsychiatric disorder	Noise, vibrations, NO_x, VOCs, manganese
Ophthalmic diseases	Dusts, irritating gases, smoke, vapours, H_2S, inadequate lighting, shining
Skin ailments	Particulate matter, nickel, chromium, acids vapours, SO_2, NH_3, VOCs
Acute and subacute intoxications	CO (most common), CH_4, smoke
Cancer	Dusts, VOCs, heavy metals
Digestive ailments	Toxic fumes, noise, high temperatures, SO_2
Deafness	Noise

2.1. Chemical risk factors

Air pollutants with risk resulting from the metallurgical activities and processes are: particulate matter, CO, SO_2, NO_x, H_2S, NH_3, VOCs, vapours of acids. Depending on the duration of exposure, for all these pollutants there are limit values and maximum permissible concentrations in ambient air. There are also systems for pollutants treatment which are continuously improved and upgraded. Their utilisation at optimum regime keeps ambient air in the workplaces and in neighbourhood areas at the recommended parameters by reference standards from the environment legislation. Although new solutions are looked for permanently, the complete elimination of the pollutants emissions is not possible. The risks associated with them must be communicated and understood by all those who work or come into contact with the work environment from the ferrous metallurgical plants. At the same time must be taken all specific security measures.

Particulate matter. In the ferrous metallurgy the major sources of particulate matter are: stock piles of raw materials (ores, coals, limestone etc.); operations for materials preparation (crushing, sieving) and transport; coke production; sinter production; pig iron castings and slag; pig iron pretreatments (desulphurization etc.); loading and unloading of converters; oxygen blowing; maintenance and cleaning of the equipments of the air quality control; demolition and reconstruction of refractory linings. The particulate matter are more dangerous if they are finer and if are associated with the heavy metals, SO_2, NO_2, NH_3. As seen in Table 1 many diseases associated with occupation may be caused by the presence in the breathed air at workplace of dust, smoke, mist or ash-fly. The particulate matter can mainly give respiratory diseases and diseases of the liver, skin, brain, eyes too.

Carbon monoxide results from incomplete oxidation of carbon, generally from combustion processes and from certain metallurgical processes. The sources of diffuse or controlled emissions include almost all sectors of the metallurgical plants: coking batteries, sintering, blast furnaces, basic oxygen furnaces (BOF) and the operations from the secondary metallurgy. Carbon monoxide is a very dangerous gas because it is colourless, odourless and tasteless. Therefore it can not be seized by the victims. It enters the body through the respiratory tract. From lungs it passes into blood where it leads to blocking the haemoglobin (suffocation), disruption of the muscle metabolism (especially to the heart) and to blocking of some enzymes. The most severely affected organs are the heart, brain and lungs. Harmful actions occur at concentrations of 0.06 % CO in air. The acute and subacute intoxications and death can occur depending on the concentration and exposure time.

Carbon dioxide is not a harmful gas for human health but it is strongly responsible for climate changes that present a major risk for environment. It is present on whole flow of steelmaking plant as a result of the combustion processes and of the metallurgical processes.

Sulphur dioxide has as main source of emission the coke production, sintering and various combustion processes of fuels with sulphur content. It is part of irritant gases category, its presence is felt because of its suffocating odour, and its odour becomes perceptible from 6 - 15 % SO_2 in breathable air. The short term exposure at an average of 10 - 30 min (24 hours) and the long-term exposure (years) irritate respiratory tracts, eyes and can cause premature death. For example, an exposure for 10min at 1000μg/Nm^3 at workplace causes severe effects (bronchitis, tracheitis). Effects of the SO_2 differ from one person to another. These are more serious for persons who already have respiratory problems and for older persons. Also sulphur dioxide can give digestive problems because it is dissolved in saliva and so can be swallowed. In addition, skin is directly affected because by dissolving into sweat it is transferred into the body in the form of acid. The SO_2 association with particulate matter has a synergetic effect that leads to the penetration and deposition of particles in the human respiratory tract and the lungs determine serious respiratory and cardiac diseases.

Nitrogen oxides are formed in the iron and steel production processes that involve the presence of air and of the high temperatures. One of these is sintering of ferrous ores. Also the fuels combustion in diverse installations may be mentioned. In this case the NO or NO_2 are formed in accordance with the conditions of combustion and NO formed is further transformed into NO_2, a brown irritating gas. This is the precursor of ozone and by reaction with water from atmosphere is partially transformed into nitric acid. If NH3 exists into atmosphere has formed NH4NO3 as particulate matter (PM2.5 fraction). Workers may be affected directly by NOx or by secondary pollutants what have been formed (ozone, photochemical fog, and particulate matter). Human body is affected by the nitrogen oxides, especially by quantity and less by the exposure period or by accumulation. They lead to respiratory or cardiac diseases, in blood oxide has a similar effect as CO. In lungs the effects may be reversible or irreversible.

Hydrogen sulphide is released mainly from granulation of blast furnace slag. This gas has an unpleasant odour which can cause various diseases in human body depending on its concentration and exposure time. The main diseases are those respiratory, from the irritation of respiratory tracts, pneumonia, lung injury, until death. Also eyes are affected and hydrogen sulphide can cause the temporary loss of smell.

Ammonia has as potential significant sources the coke-oven plant and the chemical installations for extraction of the chemical products from coke gas. It is an irritant gas that can create serious problems because of its odour (which may be felt from 18.5 mg/Nm^3). Permissible occupational exposure limit in accordance with WHO regulations is $70mg/Nm^3$ for 8 hours. The exposure for 30 minutes at $2800mg/Nm^3$ causes death. Ammonia affects upper respiratory tract, eyes and skin.

Volatile organic compounds (VOCs) may be emitted from all stages of production processes from the steel manufacturing plant. They are present in the off gas resulted in the sintering process because of the to oil content from input materials (mainly from mill scale), from coke ovens and from installations for chemical processing of coke gas. They may act on the human body directly or by their transformation products. The main compounds resulted from coking processes and from coke gas processing are aromatic hydrocarbons (benzene, xylene, toluene) which by skin contact or inhalation on short-term exposure cause various ailments of respiratory tract, nervous system, skin diseases and narcotic effect. A long-term exposure to benzene affects central nervous system (fatigue, insomnia, loss of memory) and the blood (anaemia, leukaemia).

Polynuclear aromatic hydrocarbons (PAHs) include the benzo(a)pyrene and naphthalene. If naphthalene is formed specifically at the coke plant, benzo(a)pyrene is present in many sectors of integrated steel work: coke plant, blast furnaces, steelmaking sector. This compound is extremely dangerous and is prohibited by the rules of occupational safety and by the security work normative. There are serious both short-term exposures (skin irritation and upper respiratory tract, dizziness, headaches) and long-term exposures and high concentrations (respiratory collapse, cancer, damage to liver, kidneys, lungs, and blood and lymphatic systems).

Acid vapours are specifically from the sectors of stripping (in rolling mills and galvanization sectors), maintenance, repairs and laboratories. The most used acids are: HCl, H_2SO_4, HF. These emissions affect upper respiratory tract, lungs, kidneys, liver and the skin.

2.2. Physical risk factors

Along with chemical risk factors there are important risks related to the exposure to physical agents: noise, vibration, temperature.

Noise is almost ubiquitous in steelmaking industry. The most important noise sources are: operation for gas evacuation from the blast furnace by opening a relief valve for the pressure equalization; exhaust fans for installations of the air quality control; pretreatment of iron scrap; handling, crushing and sieving of input materials, products and by-products. As example, the noise in the vicinity of exhaust fans with high capacity from sinter belts can reach values of 100-110 dB. The noises may also appear due to abnormal functioning (explosion to the slag tapping). Depending on the characteristics and propagation mode these noises affect the population surrounding the metallurgical plant. The main characteristics of noise affecting human body are: the intensity and the frequency. Endurance limit of human hearing is 65 dB. Occupational safety regulations impose safe exposure level of 75 dB for 8 hours and of 85 dB as action threshold.

Vibrations lead to health problems at long-term exposure. They are generated by the use of vibrating tools, the mobile components and equipment that operate by pneumatic, hydraulic and electrical actuators. If the vibrations are associated with humidity and cold the health effects are higher.

High temperatures at workplace are common in the steel industry. Many operations and equipments are the sources of high temperatures: coke ovens;

unloading, conveying, crushing, sieving and quenching of hot coke; tapping and conveying of the pig iron and blast furnace slag; pouring of the steel and BOF slag; other pyrometallurgical processes from BF and BOF sectors; hot rolling of the steels; thermal treatment furnaces etc. Temperature exposure affects the human body (syncope, oedema, dehydration, rash) and thermal shocks give thermoregulatory difficulties. Equally dangerous are low temperatures and air currents at unprotected workplaces (raw materials stock yards, dump slag).

Shine of the molten alloys and glow of products and by-products are also often situations frequently in work places from steel industry that directly affect (eye diseases) or indirectly (reduced visibility) the safety.

Radioactivity was detected as a result of accidental introduction of scrap with radioactive sources. Also it is considered for laboratories and the handling of radioactive sources related to control systems (smoke detectors, measuring apparatus for level, humidity and thickness).

3. Risk assessment and risk analysis

The risk assessment is made in terms of severity and probability, by combination of the two factors in risk matrices. Severity refers to the consequences of hazard occurrence and the probability refers to the frequency with which these may occur. In our country, the risk assessment is evaluated by the method of determining the level of risk which shows seven grades of severity, six grades of probability and six levels of risk [11]. Grades of severity are related to the following possible consequences of risk production:

- 1st class: negligible consequences; (incapacity for work less than 3 days)
- 2nd class: small consequences; (incapacity of between 3 - 45 days, which requires medical treatment);
- 3rd class: medium consequences; (disability of 45 - 180 days, medical treatment and hospitalization);
- 4th class: high consequences (disability grade III);
- 5th class: serious consequences (disability grade II);
- 6th class: very serious consequences (disability grade I);
- 7th class: maximum impact death.

In terms of probability classes it was opted for the following form:

- 1st class of probability: event frequency over 10 years;
- 2nd class: generation frequency – once in 5 ÷10 years;
- 3rd class: once in 2 ÷ 5 years;
- 4th class: once in 1 ÷ 2 years;
- 5th class: once in 1 year ÷ 1 month;
- 6th class: once in less than a month.

According to the 7 classes of severity there were established 7 risk levels, in ascending order, because the severity is a more important element in terms of environmental and labour protection and it was admitted that it has a greater impact on the level of risk than the frequency:

- N_1 - minimal risk level; s-p couples: (1,1) (1,2) (1,3) (1,4) (1,5) (1,6) (2,1);
- N_2 - very small risk level; s-p couples: (2,2) (2,3) (2,4) (3,1) (3,2) (4,1);
- N_3 - small risk level; s-p couples: (2,5) (2,6) (3,3) (3,4) (4,2) (5,1) (6,1) (7,1);
- N_4 - moderate risk level; s-p couples: (3,5) (3,6) (4,3) (4,4) (5,2) (5,3) (6,2) (7,2);
- N_5 - high risk level; s-p couples: ((4,5) (4,6) (5,4) (5,5) (6,3) (7,3);
- N_6 - very high risk level; s-p couples: ((4,5) (4,6) (5,4) (5,5) (6,3) (7,3);
- N_7 - maximum risk level; s-p couples: (6,6) (7,5) (7,6).1 ;

If were considered all possible combinations of specified variables, taken two, was obtained a risk matrix, $M_{s,p}$, with 7 lines - s, which will represent severity classes, and 6 columns - p for probability classes:

$$M_{s,p} = \begin{Vmatrix} (1,1) & (1,2) & (1,3) & (1,4) & (1,5) & (1,6) \\ (2,1) & (2,2) & (2,3) & (2,4) & (2,5) & (2,6) \\ (3,1) & (3,2) & (3,3) & (3,4) & (3,5) & (3,6) \\ (4,1) & (4,2) & (4,3) & (4,4) & (4,5) & (4,6) \\ (5,1) & (5,2) & (5,3) & (5,4) & (5,5) & (5,6) \\ (6,1) & (6,2) & (6,3) & (6,4) & (6,5) & (6,6) \\ (7,1) & (7,2) & (7,3) & (7,4) & (7,5) & (7,6) \end{Vmatrix}$$

The formula for calculating the overall risk level is:

$$Nr = \frac{\sum_{i=1}^{n} r_i \cdot R_i}{\sum_{i=1}^{n} r_i} \quad (1)$$

where: Nr is the global risk level on the workplace; r_i is the risk factor rank "i"; R_i is the risk level for the risk factor "i"; n is the number of risk factors identified at the workplace.

For the assessment of the occupational risk that is associated with the workplace have been identified the hazards correlated with the workplace for a maintenance worker (e.g. a welder) because they are all steel sectors which were previously assessed risk factors. To identify the hazards the have been established class of the level, class of probability and risk level.

The results are given in Table 2.

Table 2. *Severity class, probability class and risk level for identified hazards*

Code.	Hazard	Severity	Probability	Risk level
1.	Particulate matter (fine and very fine fractions) in ambient air of the workplaces (interventions at cleaning systems for gases)	3	6	4
2.	Irritant gas resulted from the production processes (NH_3, SO_2, H_2S)	3	6	4
3.	Presence of carbon monoxide in some areas of workplaces	7	3	5
4	VOCs, PAHs, PCDDs/F in ambient air of workplaces	7	1	3
5.	Toxic gases arising during welding or oxy-fuel cutting of metals	7	6	7
6.	Working in areas where toxic substances are present (mineral oils, acids, greases)	7	1	3
7.	Working in areas where corrosive substances are present (mixture of water and phosphates from cooling installations)	7	1	3
8.	Possibility of accumulation of flammable gases and vapours and/or explosives to some workplaces (accumulation of methane, oxygen in closed spaces), fire hazard and/or explosion	7	6	7
9.	Working with flammable substances and/or explosives or at installations that use flammable (oxygen, methane, oils, greases)	7	1	3
10.	Leakage of methane, oxygen by cracking of supply systems, oil jet from accidental cracking of hydraulic circuits, hot water jet or steam from process lines	6	1	3
11.	Working in the vicinity of pressure vessels	7	1	3
12	Flames and fires from the process or as a result of ignition of flammable substances, damages of the electrical installations in the work area (burn or fire hazard)	6	1	3
13	High temperature of the objects, materials, surfaces from the work environment or of the products and by-products resulted from the manufacturing process	2	6	3
14	High temperature of ambient air in some work areas (near furnaces and other thermal aggregates)	2	6	3
15	Low temperature of the metal surfaces in cool season	2	5	3
16	Low temperature of ambient air in cool season	2	5	3
17	High humidity of the air at making works in the household water	2	5	3
18	Air Currents (defective enclosures, doors open)	2	6	3
19	High level of noise	4	6	5
20	Low level of lighting in some areas of workplaces	2	6	3
21	High contrast between background material and general lighting of the working place	2	6	3
22	Non-ionizing radiations (IR and UV) from the process or near furnaces, rolling lines etc.	2	6	3
23	Working in areas where there is risk of drowning (cooling towers, tanks, basins, clarifiers etc.)	7	1	3
24	Natural disasters: earthquake, lightning, hail, storm etc.	7	1	3

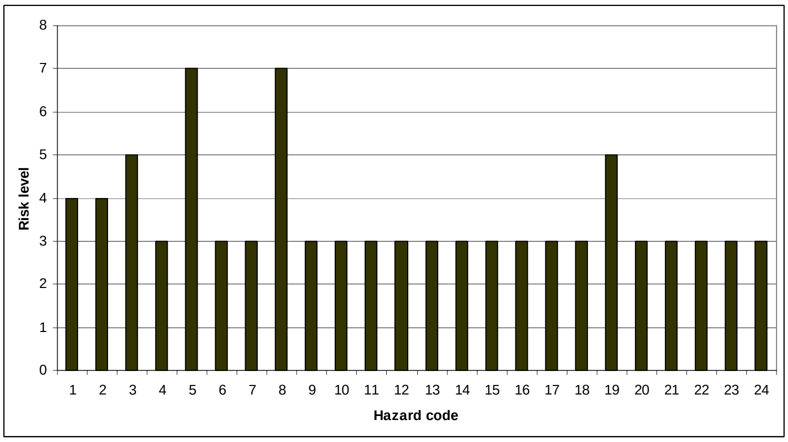

Fig 1*. Level of analyzed risk hazards as function of severity and probability*

The level of risk for each hazard identified in the work environment is shown in Figure 1. In any assessment action, significance will be attributed to considerable risks with a great impact on workers and environment. To identify these risks, the ranking scale of risks at the workplace is made (Table 3).

This gives the possibility to establish the priority of prevention and protection, according to the risk factors that have the highest risk level.

***Table 3**. Ranking scale of risks*

Risk level	Hazards code
7 - Maximum risk level	5 and 8
5 - high risk level	3 and 19
4- moderate risk level	1 and 2
3- small risk level	5, 6, 7, 9-18, 20-24

The level of global environmental risk calculated in accordance with relation (1) is 3.84. From risk assessment results a total of seven significant hazards (unacceptable) related to workplace. Other risks associated with the work environment shows a low level of risk that is considered acceptable. The most dangerous workplaces are those that generate toxic gases that accumulate into enclosed spaces, also the flammable gases with potentially explosive or fire. The carbon monoxide in the work environment has a high risk level and requires protective measures for monitoring such as the audible warnings. A level of high-risk shall submit and the noise. Measures that may apply to this risk factor consist in minimization by isolation of the sound sources or utilization of soundproofing materials. Also there may be applied the individual protection measures with special equipment (for protection of ears) associated with alternative periods of exposure and rest. The presence of the irritant gases and the particulate matter in the work environment requires a set of measures to reduce the risk associated with them. These emissions can not be eradicated in the steel plant but can be significantly minimized by using the best technologies that ensure a clean work environment. Unfortunately a barrier in taking such measures is the high costs.

4. Conclusions

- Risk assessment associated to work environment in steelmaking emphasizes several dangers to workers through: pollution of air with toxic gases and with the potential of explosion and fire; uncontrolled emissions of CO; fine and very fine particles in the ambient air; high noise.

- Toxic gases (VOCs, PAHs, PCDDs/F) that are potentially flammable and explosive (methane gas, blast furnace gas, oxygen) have the maximum risk level. They can cause death and present the potential hazards with high probability.

- The presence of CO in the work environment are also very serious consequences (death) but this gas emission hazards are well monitored and have a lower probability of occurrence. The level of risk is still high requiring continuous monitoring.

- Releases of the particulates and the gases to the work environment from diffuse sources or controlled sources are impossible to be eliminated in the steel industry but by application of the best technologies they can be much reduced.

- Work environment may involve important problems of work security that requires implementing an occupational risk management.

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