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HEALTH IMPACT OF PARTICULATE POLLUTANTS

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This paper refers to the industrial ecosociology, i.e. the interactions among three systems: natural-ecological (particulate pollution), technological (particulate pollutant generation in a steel plant) and social (health status under the adverse impact of the particulate pollutants). The impact of particulate matters is analysed based on the concentration cp [μg/m3] and the exposure time of the receiver, de [days]. The following aspects are dealt with: the need of engineers to know some metallurgical ecosociology targets; the correlations between the particulate matter properties and health status (diseases and ecostress); the graphical processing and interpretation of industrial measurements. As a general conclusion, we show the importance of gas cleaning techniques in reducing the adverse impact of the particulate pollutants.

Keywords: Ecosociology, particulate matters, pollution, disease, ecostress

1. Introduction

The **sustainable development** of the human existence sphere is a new concept (model), under which the development is the result of interactions and interrelations developed in the *intersystem areas* found in the *convergence sphere* of four basic systems: natural-ecological, social, economic and technological.

An important situation met today in the major concerns of the researchers in the metallurgical industry aimed at the convergence area subject to sustainable development of three fundamental systems (natural-ecological, social and technological) which, in this paper, is analysed according to:

- pollution with particulate matters generated and dissipated in the manufacture of ferrous materials (steel), as part of the natural-ecological system;

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- health status (disease and stress), as a social system element;
- processes, technologies and equipments, as part of the technological system; the attention is mainly given to the gas cleaning techniques (equipment) [9].

The major purpose is to know the indirect interactions (interconditionings) (through the natural-ecological system) between the generation of particulate matters in the technological system and the health status. Therefore, we speak about researches planned according to a knowledge flow, as shown in Fig. 1.

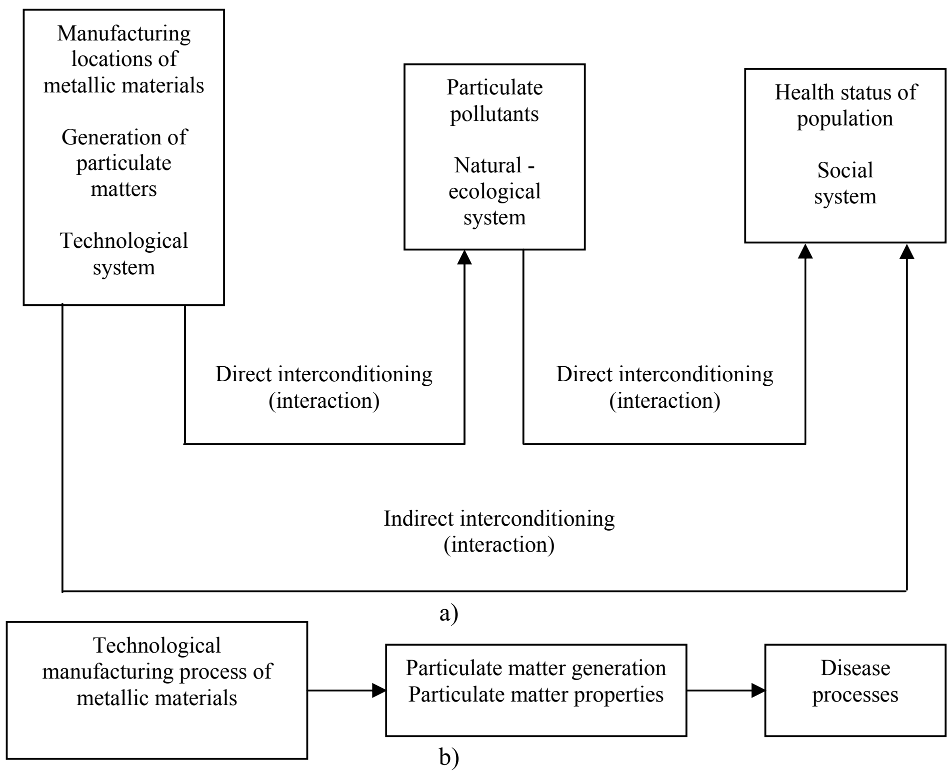


Fig.1. The flow of interconditionings studied in this paper:
a) general form; b) applied form

The objectives such as the above are subjects of study for a new discipline, called Industrial Ecosociology. This branch of science deals with the knowledge of events occuring in the area of convergence among the natural-ecological, social and technological systems, the latter being represented by the industrial processes contour.

A sub-branch of the Industrial Ecosociology is the Metallurgical Ecosociology, for which the technological system is represented by the metallurgical industry. [1]

2. Background for planning and conducting the researches

As part of industrial ecosociology, the particulate matters have a triple role: ecological agent (pollutant); social agent (adverse impact on the health status); technological agent (substances generated as losses in the technological processes). Therefore, it is imperative for the researcher to have knowledge in three areas: ecology, sociology and engineering. We briefly present below the knowledge based on which we can investigate the impact of particulate matters on some social indicators. The **industrial particulate matters** are mixtures of solid or liquid particulate matters dispersed in the gaseous phase, with which they form a *polydispersed system*. The main component is represented by the particulate matters. The **particles,** also known as *particulate matters* and abbreviated as *PM,* are the solid components finely dispersed in the gas phase. The **technological particulate matter (process particulate matter)** is the particulate matter emitted inside the technological enclosure where the manufacturing processes of metallic materials occur. The **parameters** determining the impact of particulate matters on some social indicators were the subject of study for many papers, including of medical nature [2-8]. For this study, the following parameters have been used:

Specific lateral area, $A_{l.a}$, is the area of the side surfaces of all the particles existing in the mass unit of particulate matter. It follows that it is measured in [m^2/kg]. Given that the diseases are processes of the heterogeneous systems (biphasic or triphasic) that depend on the contact area between the phases, it is inferred that this property is very important in assessing the health status under the influence of P.M. The **individual particle mass**, m_p, and the particle overall mass in a given volume, $m_{p.g}$, are measured, as a rule, in [μg]. The **particle size**, due to its irregular contour, it is assessed by two conventional parameters. The *particle aerodynamic diameter,* $d_{a.p}$, is the diameter of the sphere with the density of 1g/cm^3 having the same free fall limit speed in the gravitational field as the studied particle [8]. The *particle equivalent diameter,* $d_{e.p}$, is the globular particle diameter that would incorporate the mass of the monitored irregular particle. Its calculation is based on the experimentally knowledge of $A_{l.a}$, taking into account the specific number of particles n_p, present in the mass of 1 kg, and the density of the particle, ρ_p. The **specific number of particles**, n_p, is the number of particles per unit weight [number/kg]. The **particulate matter concentration**, c_p, measures the weight of the particles existing in the unit volume or mass, for the three major environmental factors: air, water, and ground. It is measured in [μg/m^3] or [μg/kg].

$$
\begin{aligned}
A_{l.a} &= n_p \times 4\pi \frac{d_{e.p}^2}{4} = n_p \pi\, d_{e.p} \\
n_p &= \frac{1}{\frac{\pi\, d_{e.p}^3}{6}\rho_p} = \frac{6}{\pi\, \rho_p d_{e.p}^3} \\
A_{l.a} &= \frac{6}{\pi\, d_{e.p}^3 \times \rho_p}\pi\, d_{e.p}^2 \\
d_{p.conv} &= \frac{6}{A_{l.a} \times \rho_p}
\end{aligned}
\tag{1}
$$

The **particle size structure** is the property which characterises the distribution of particles by size classes, weight or number. Analytically, it is characterised in defining certain *size classes (fractions)* (Table 1).

Table 1

Personal classification of the technological particulate matters T.P.S. (Total Suspended Particulates)

Name		Symbol	Particulate matter size [µm]
Coarse particulate matters (P I)		PM 35	more than 12
Large particulate matters (P II)		PM 10	4 – 12
Small particulate matters (P III)	Fine particulate matters	PM 2.5	0.1 – 4
	Ultrafine particulate matters	PM 0.1 or UFP_s	less than 0.1

The granulometric spectrum *(g.s.),* based on the diagram shown in Fig. 2, represents the successively and decreasingly presentation of the grain-size fractions.

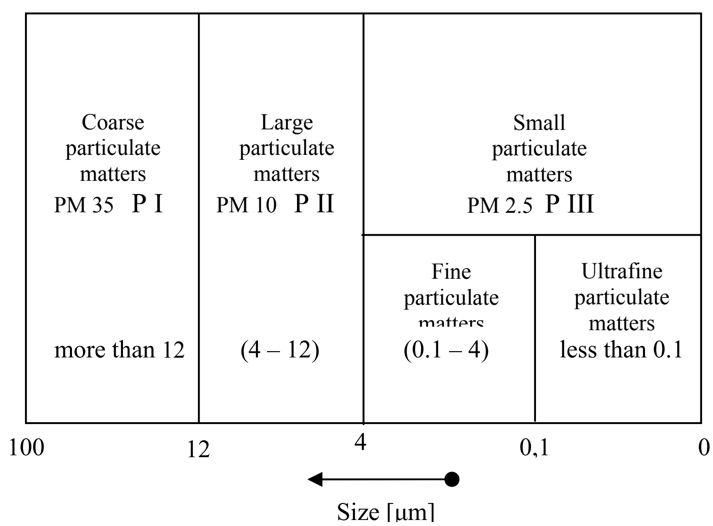


Fig.2. Granulometric spectrum diagram

The spectrum shifting to the right means the increasing trend of the fine and ultrafine fractions. The spectrum shifting to the left means the increasing trend of the large fractions. The **ecosocial status** is the parameter that characterises the level of social needs satisfaction of the members of a community under the condition of natural-ecological system pollution. The **health status** is one of the parameters used to assess the ecosocial status. The **degree of disease** and the **number of diseases** are parameters based on which we can make several assessments concerning the health status. The **ecosocial parameter** characterises the process of installing a social effect under ecological change conditions. The **degree of disease** is the parameter that characterises the level of health damage caused by pollution. Since this paper deals with the pollution effects on the health status, hereinafter we are going to use the notions of *disease degree* and *health status*. The **disease probability, P_r,** is the parameter which characterises the possibility of disease. The **duration of exposure, d_e,** [hours, days] is the parameter that characterises the period of contact between the receptor and pollutant. The **disease severity** is the parameter that assesses the unpleasant and dangerous consequences of the disease. The **degree of disease severity** is the parameter used to assess the disease severity on a relative ranking assessment scale. In this paper, we *propose* three degrees of severity:

- diseases with first degree of severity (BGG I), which means diseases with low degree of severity;
- diseases with second degree of severity (BGG II), which means diseases with medium degree of severity;
- diseases with third degree of severity (BGG III), which means diseases with high degree of severity.

Taking into account some information from the medical literature, the authors considered the issues presented below.

♦ The possible connection between the granulometric structure and nature of diseases is presented in Table 2.

Table 2

Classification of fractions by probability and nature of diseases

Name	Size [μm]	Information
Inhalable fraction	up to 100	Fractions totally inhalable. Particulate matters that create general favourable conditions for disease.
Thoracic fraction	approx. 10	Particulate matters that reach the upper level of the respiratory system (pharynx, larynx, bronchi), causing diseases (bronchitis, laryngitis, pharyngitis, etc.).
Breathable fraction (alveolar)	less than 4	Particulate matters that, when reaching the alveoli, may cause a disease. The occupational diseases are included in this category.

♦ The severity of disease is directly proportional to the concentration of the particulate matters, c_p.

♦ The severity of disease is inversely proportional to the particle size, d_p.

♦ The severity of disease is directly proportional to the exposure time of the receiver, d_e.

♦ The probability of inducing a certain degree of disease severity can be ranked analogously to the other situations:

- first degree probability, P_rG I (low probability);
- second degree probability, P_rG II (medium probability);
- third degree probability, P_rG III (high probability).

♦ From the foregoing, it is inferred that the probability of inducing a certain degree of severity is influenced by the size and composition of the particulate matters. Therefore:

✓ The probability of diseases with high degree of severity (BGG III) increases with increased share of small particulate matters (fine and ultrafine);

✓ The probability of diseases with low degree of severity (BGG I) increases with increased share of coarse particulate matters.

♦ It can be also recognized that:

▪ the shifting to the left of the granulometric spectrum (increase of P I) entails the increase of probability to occur less serious diseases (BG I);

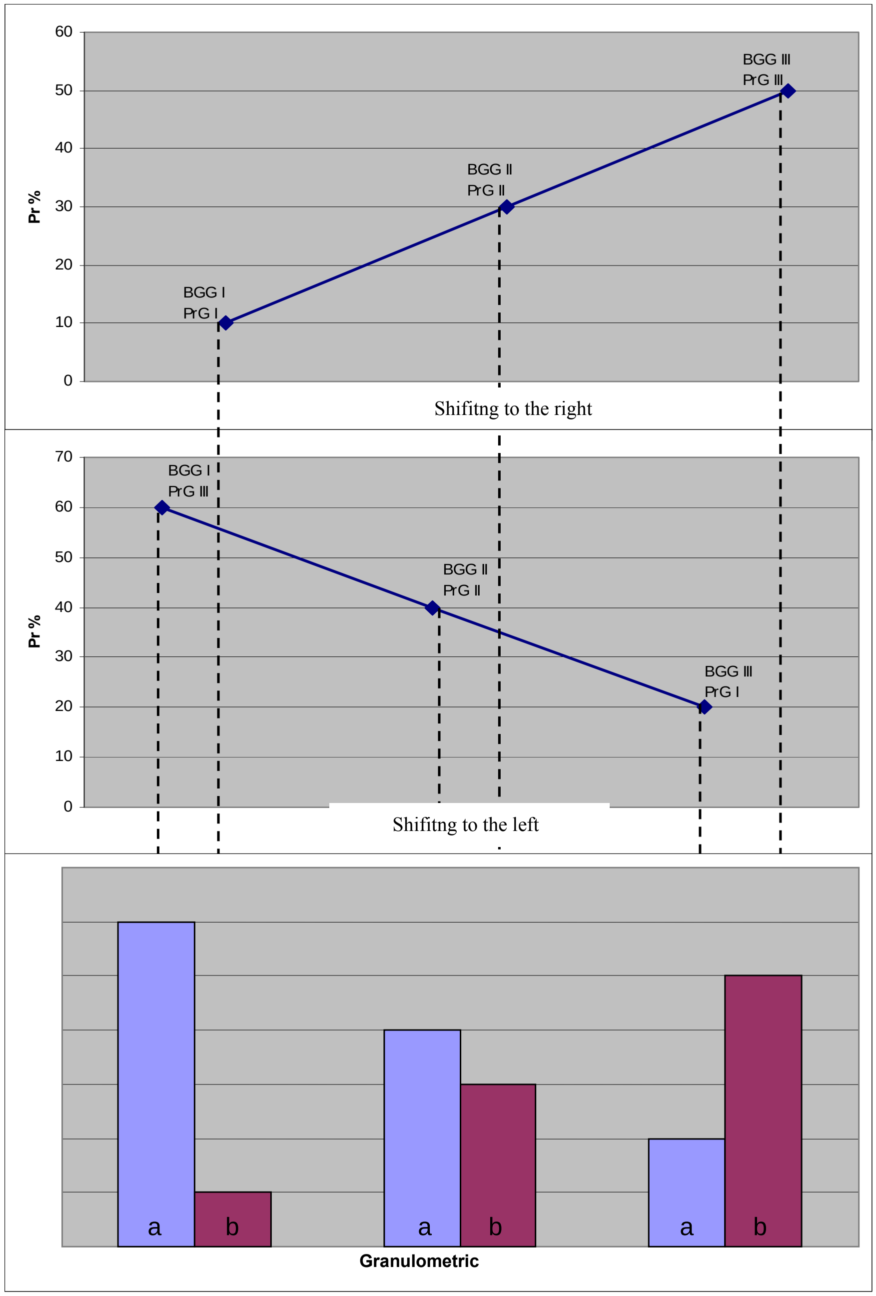
▪ the shifting to the right of the granulometric spectrum entails the increase of probability to occur very serious diseases (BG III).

♦ These observations are processed tabulated in Table 3 and graphically in Fig. 3.

Table 3

Personal classification for the levels of disease

Particulate matter	***Disease circumstances***	***Level of disease Symbol***
Coarse particulate matters	Favourable disease circumstances provided by the inhalable fraction (particulate matters P I)	Low severity diseases, Diseases with first degree of severity, BGG I.
Large particulate matters	Favourable disease circumstances provided by the thoracic fraction (particulate matters P II)	Medium severity diseases, Diseases with second degree of severity, BGG II.
Small articulate matters (fine and ultrafine)	Favourable disease circumstances provided by the alveolar fraction (particulate matters P III)	High severity diseases, Diseases with third degree of severity, BGG III.



a) shifting to the left of the spectrum (P I - major)
b) shifting to the right of the spectrum (P III - major)

3. Results of experimental research

The research focused on how the industrial activity from a mini steel plant equipped with electric arc furnace (EAF), used for making steel for further obtaining cast billets, influences the health status of the community.

We analysed the influences of the concentration, c_p, and exposure duration, d_e.

It is noted that the information about the particulate matter concentration refers to the concentrations measured at a distance prescribed by norms from the industrial hall contour.

The information on particulate matter concentrations recorded in the mini steel plant *are taken from the recordings made in the monitoring points of the national network for the assessment of air quality. These data are public and have been extracted from the air quality database of the European Environment Agency AirBase.* [10].

3.1. Precursor Gas Measurements

The literature reports cases in which certain gases can become germination and development centres for the particulate matters [11, 12]. Considering this role, they are appreciated as *precursor gases* for the particulate matters. This includes the SO_X and NO_X gas families. This paper does not deal with the mechanism by which these gases work. But, the development researches conducted in a steelmaking plant are necessary for:

- obtaining data regarding the NO_X and SO_X concentrations within the area of plant; this was made by using the information sources [10],
- processing these data;
- establishing correlations between the gas concentrations and the trend of disease probability;

The precursor gas role for the particulate matters cannot be dissociated from the overall effect on health of the NO_X and SO_X. In this context, the research results must be regarded as referring to the global role, which includes the precursor gas role.

It is noted that:

- the analysis is time-correlated (we chose a significant period);
- the change in gas concentration is the result of *technical measures of gas cleaning* taken by the plant staff; these measures are not described in this paper, because they were independent of the authors' work;
- in this paper, we analysed the effects produced by operationalization of some gas cleaning techniques applied in the plant;
- the statistical analyses were performed for the years 1990-2012 and included data on air quality and concentrations of pollutants found in atmosphere;

it was analysed the distribution of daily values by using *percentiles, annual average values* and *maximum values*.

The measurement results are shown in Tables 4 and 5.

Table 4

The annual average and maximum values of SO_2 [μg/m^3]

Year	Annul average	Maximum value
1999	2.4	18.7
2000	3.34	13.1
2001	2.86	20.7
2002	3.45	24.4
2003	13.43	42.8
2004	14.53	36.4
2005	12.96	125.14
2010	1.15	10.20

Table 5

The annual average and maximum values of NO_2 [μg/m^3]

Year	Annul average	Maximum value
1999	13.03	38.8
2000	12.64	36
2001	11.45	26.2
2002	10.33	21.7
2003	13.62	24.72
2004	14.50	92.60
2005	15.20	98.15
2006	17.30	91.40
2007	7.80	16.80

3.2. Measurements on particulate matters

We analysed the PM10 particulate matters. The measured values are presented summarized in Table 6.

Table 6

Information about the values measured at particulate matters [μg/m^3]

Year	Annul average	Maximum value
2004	52.18	192.8
2005	54.62	194.5
2006	38.96	150.0
2007	34.92	101.3
2009	21.05	70.32
2010	18.77	68.31

3.3. Measurements on occupational ecostress

The adverse impact of the particulate matters on the health status can be analysed in two situations:

– disease;

– stress.

So far, the literature indicates predominant concerns in terms of occupational diseases, reason why, in this paper, we granted priority attention to the possibilities of disease, which are qualitatively assessed through the disease hazard (risk curve and risk curve trend), although there is one more item to be taken into account (i.e. the stress).

The **professional (occupational) stress** is an intense and unpleasant condition arising in the professional activity, in the long term, with adverse effects on health, performance and productivity [13]. Among other things, the occupational stress depends on:

– intensity of stressor agents;
– duration of agent operation.

The **ecostress** is a specific form of stress, mainly caused by some pollutant agents with adverse effect on the work environment.

In this paper, the ecostress is correlated with:

✓ the particulate matters concentration, c_p [μg/m^3], as intensity of the stressor;
✓ the exposure duration, d_e [days], of the personnel in the pollutant environment, as stressor action duration.

The **ecostress index** is the parameter used to quantify the occupational ecostress status.

We propose to define the ecostress index through the equation:

$$I_{e.s.o} = d_e \cdot c_p, \quad \left[\frac{\text{days} \cdot \mu\text{g}}{\text{m}^3}\right] \tag{2}$$

The measurements and calculations of the ecostress index variation are shown in Table 7.

Table 7

Data about the stress index

Period	d_e **[days]**	c_p **[μg/m^3]**	$I_{e.s.o}$ **[days·μg/m^3]**
a	142	10	1420
b	320	20	6400
c	250	30	7500
d	120	40	4800
e	80	50	4000
f	30	60	1800
g	25	70	1750
h	20	80	1600

3.4. Investigations regarding the specific concentration

The data processing described above was carried out using the property of concentration c_p [μg/m^3]. This indicator is *currently used* in all the papers that analyse the emissions and imissions in the manufacturing sectors of metallic materials. However, it does not reflect *full information about the pollution status*, and therefore the interpretations cannot be considered completely enlightening.

The amount of pollutants Q_p, [m^3; kg pollutants/year], discharged into the environment, depends on several factors:

- nature and intensity of pollution generating processes, which determine the $c_{p.t}$ concentration;
- effectiveness of gas cleaning techniques, which determine the concentration in the exhaust;
- production of material P, [t·material/year];
- pollutant emission factor, f_p, measured in [m^3; kg pollutants/t·material], by means of which we determine the relation:

$$Q_p = P \cdot f_p \ , \quad \text{[m3; kg pollutants/year]} \tag{3}$$

The role of production *P* can be highlighted if we introduce the notion of *specific concentration*.

The specific concentration, $c_{p.s}$ is the concentration defined by the equation:

$$c_{p.s} = \frac{c_p}{P} \ ; \ \left[\frac{\mu\text{g} \cdot \text{year}}{\text{m}^3 \cdot \text{t} \cdot \text{steel}} \right] \tag{4}$$

The use of such property would have the following advantages:

- it would introduce the economic system (represented by *P*) in analyses, which is an important economic indicator;
- it would highlight the fact that the status of pollution depends also on the material production obtained in the analysed sector.

To highlight the importance of the specific concentration, we made measurements at the mini steel plant (EAF) and a machine-building plant (MBP), where the foundry was generating particulate matters. The measurement results are shown in Table 8.

Table 8

Measurements on the specific concentration

	[μg/m³]			
	2000	2001	2002	2003
EAF	94	130	140	1146
MBP	128	134	133	1129

4. Experimental data processing

The correlations that can be established among the various analysed parameters are plotted in Figs. 4-11.

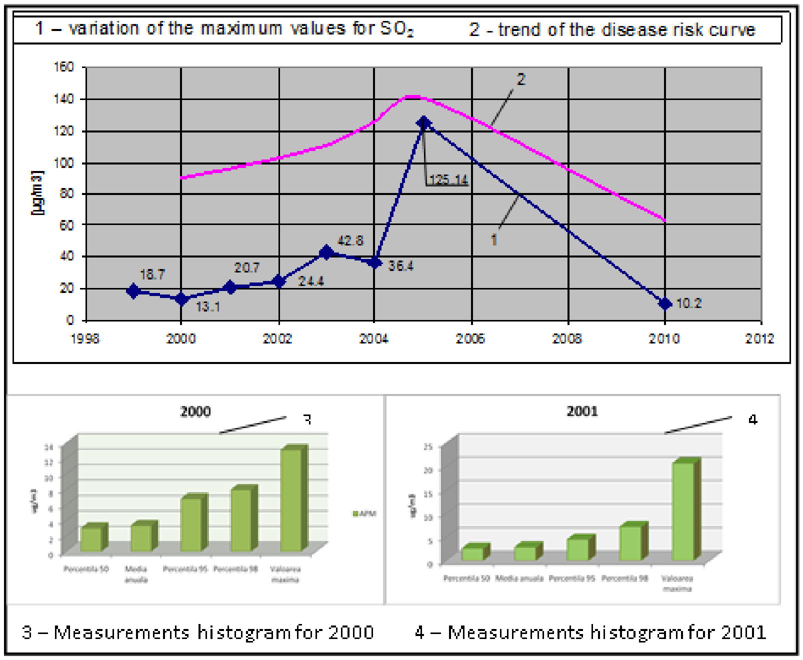


Fig. 4. Ecosocial correlations versus the maximum values for SO_2.

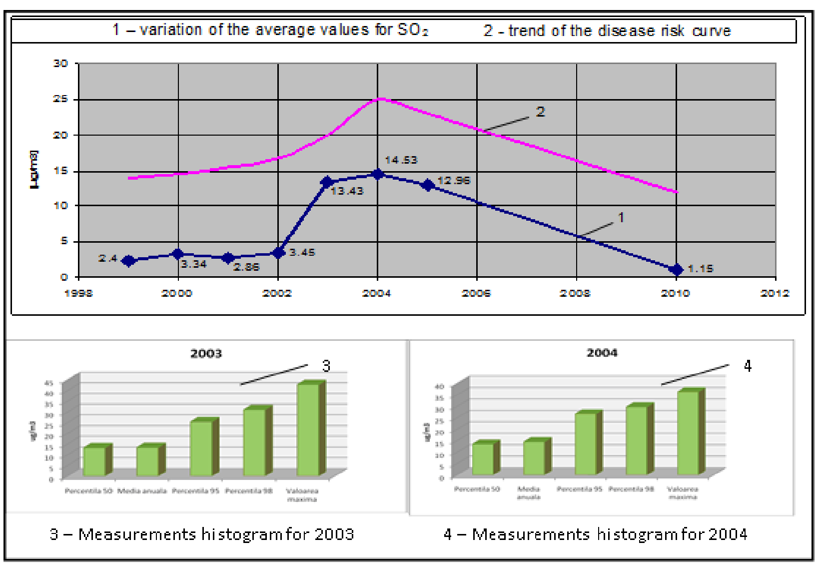


Fig. 5. Ecosocial correlations versus the annual average values for SO_2

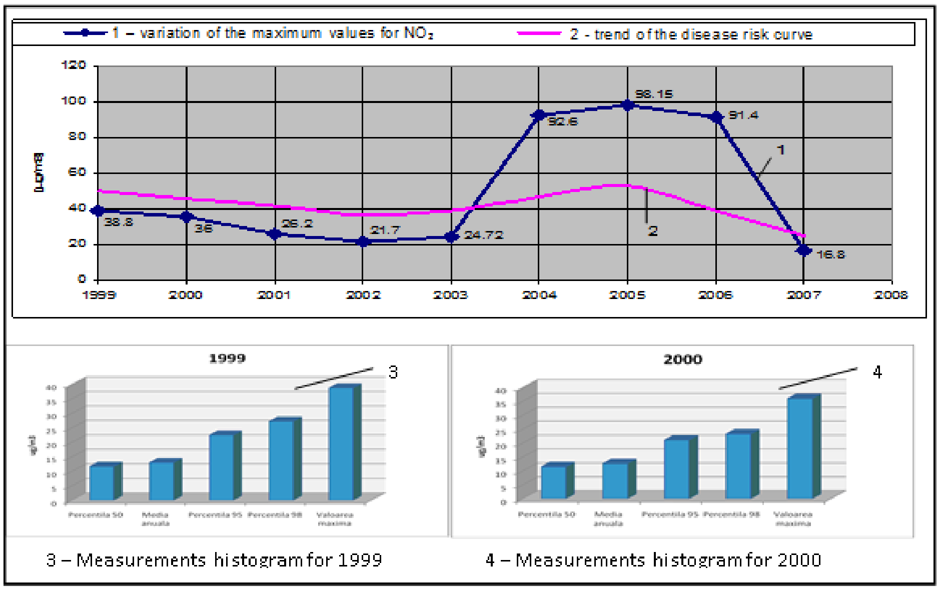


Fig.6. Ecosocial correlations versus the maximum values for NO_2.

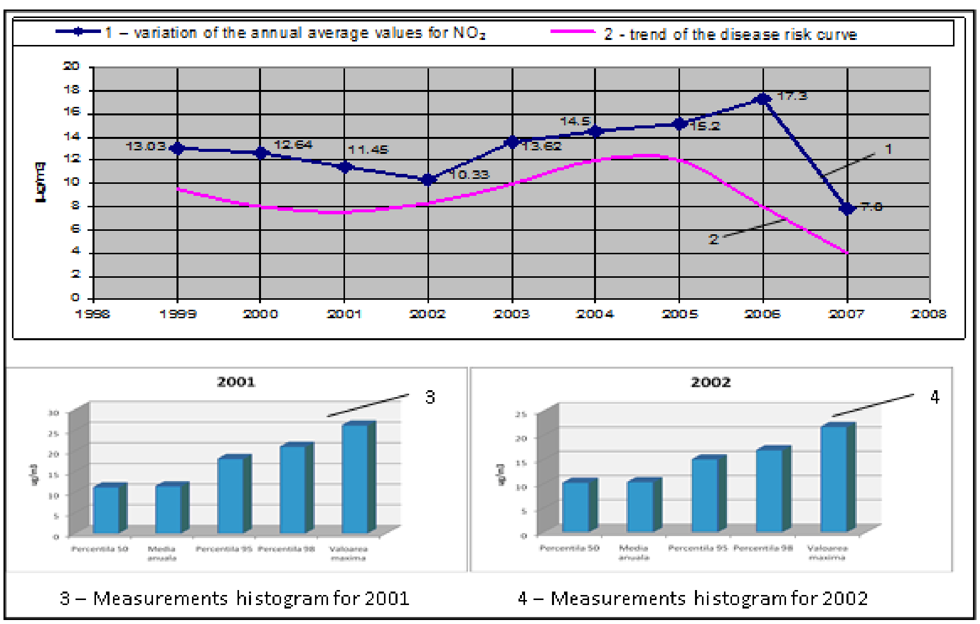


Fig.7. Ecosocial correlations versus the annual average values for NO_2

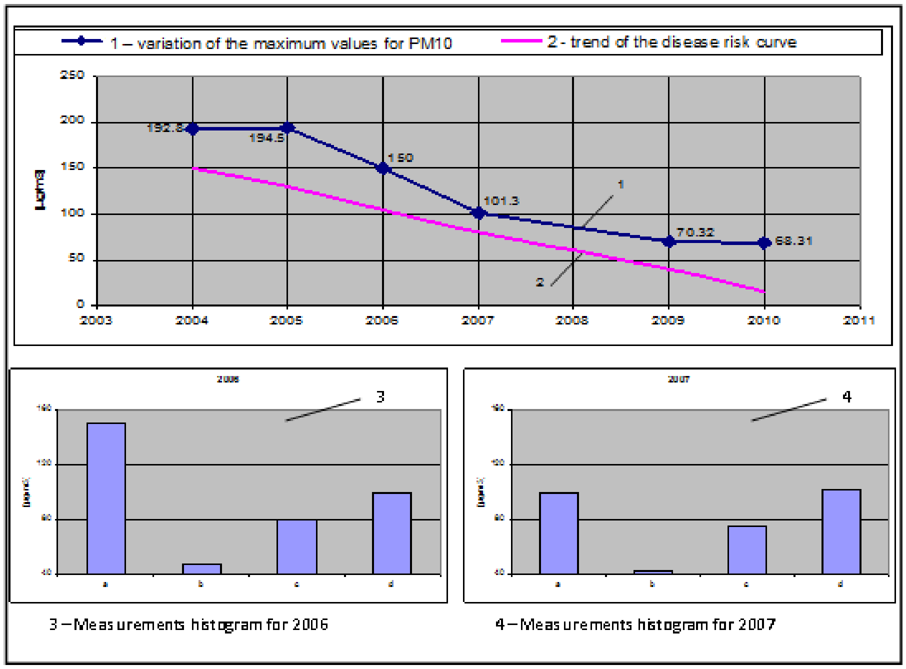


Fig. 8. Ecosocial correlations versus the maximum values for PM10

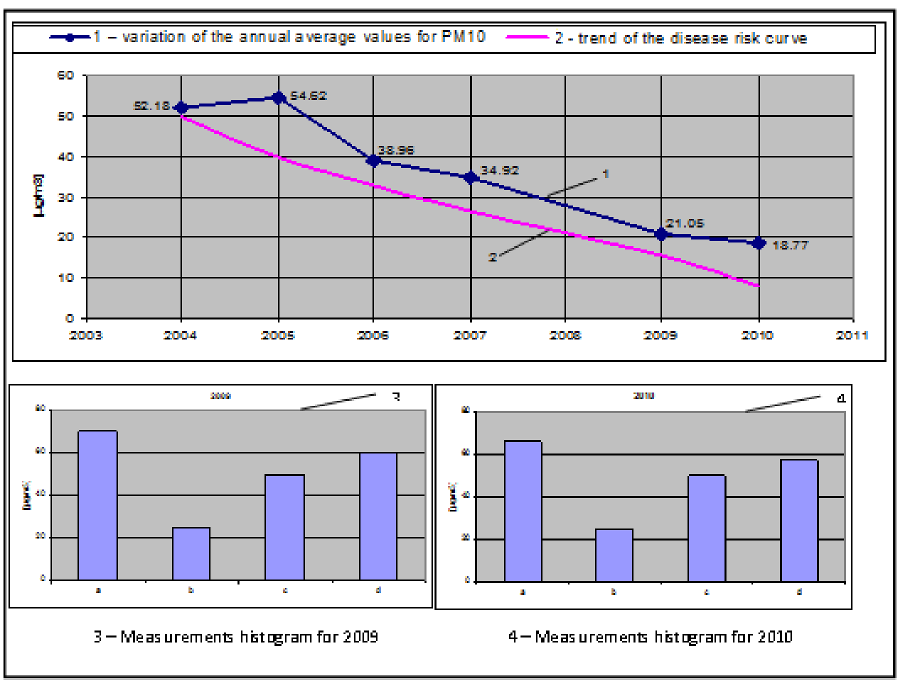


Fig. 9. Ecosocial correlations versus the annual average values for PM10

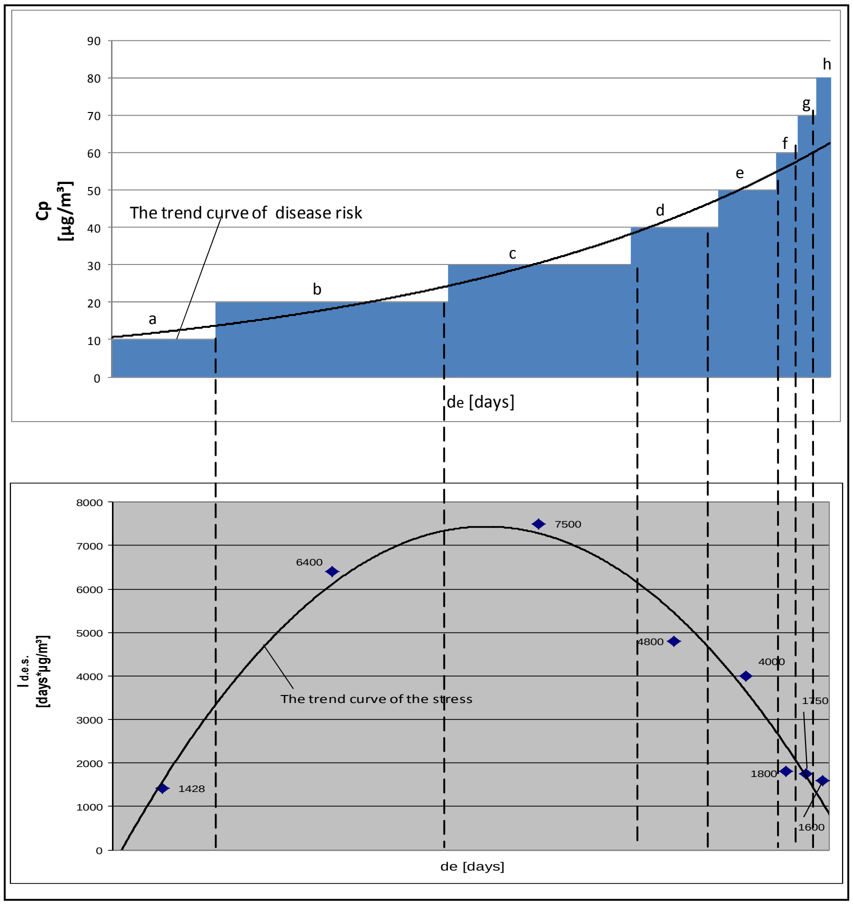


Fig. 10. Possibilities of disease and ecostress

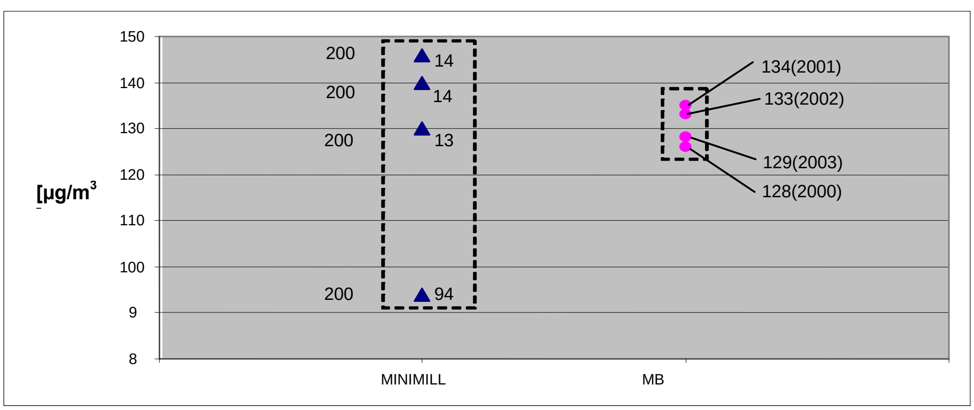


Fig. 11. Pollution measurements in two different industrial locations

5. Interpretation of results. Conclusions

♦ In 2004-2006, in the analysed location were implemented some projects on the gas cleaning technique. It was found that:

- During the period of gas cleaning technique reconstruction, there were days when the maximum values had dramatically increased;
- The annual average values had also increased.

♦ It is obvious that the precursor gas emissions are clearly depending on the effectiveness of the gas cleaning techniques.

♦ Acknowledging the direct link between the gas concentrations and risk of disease, we can demonstrate therefore that the gas cleaning technique is a major tool for reducing the risk of disease caused by the precursor gases.

♦ Since the gas cleaning technique is a matter of engineering, we conclude that the ecosocial effect, assessed by health worsening, can be seriously reduced by taking outstanding measures in the field of materials engineering.

♦ The gas cleaning techniques are more effective when applied to precursor gases than to particulate matters. In this paper, we define the *degree of effectiveness,* g_{ef}, through the equation:

$$g_{ef} = \frac{c_{\text{p.year.maximum}} - c_{\text{p.year.minimum}}}{c_{\text{p.year.maximum}}} \cdot 100 \ [\%] \tag{5}$$

The calculation results are shown in Table 9.

Table 9

Data on the gas cleaning effectiveness

Substance	Case	g_{ef} [%]
SO_2	maximum values	82
	average values	92
NO_2	maximum values	92
	average values	73
PM	maximum values	65
	average values	67

♦ The above results show that, in the manufacturing sectors of metallic materials, the prevention of PM pollution is a primary task.

♦ In the category of ecosocial events influenced by pollution in the metallurgical sectors, the *ecostress* should be also considered, which can occur even if the disease is not a significant hazard. It is noted that the ecostress index can have maximum values (Fig. 10) in an area where the concentration values are not maximum.

♦ At the same pollutant generation processes and the same gas cleaning technique, the impact of pollutants is also influenced by the *production volume,* through the *specific concentration.*

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R E F E R E N C E S

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