Mathematical Models to Analyzing the Mass Transfer into the Subsoil of Slag and Ash Sludge of Coal-Fired Power Plants

CORNELIA A. BULUCEA[1] ANDREEA C. JELES[2] NIKOS E. MASTORAKIS[3]
CARMEN A. BULUCEA[4] PHILIPPE DONDON[5]

[1] Faculty of Electrical Engineering, University of Craiova
ROMANIA

[2] Technical College of Arts and Crafts « Constantin Brancusi » of Craiova
ROMANIA

[3] Technical University of Sofia, Industrial Engineering Department
BULGARIA
and
International Center of Mathematical and Computational Medicine, Athens
GREECE

[4] Faculty of Medicine, University of Medicine and Pharmacy of Craiova
ROMANIA

[5] Université de Bordeaux, IPB UMR 5218
France

abulucea@gmail.com , andreee_83@yahoo.com , mastorakis4567@gmail.com ,
carmen.bulucea@gmail.com , Philippe.Dondon@enseirb-matmeca.fr

Abstract: Operation of coal-fired power plants determines a big amount of slag and ash, and also releases harmful flue gases. Consequently, a serious concern is related to the health of humans and other life forms that is impacted of xenobiotics caused by burning coal in electrical generating stations. The concept of xenobiotics has been extended to the environment over the last several decades, and many studies are demonstrating that xenobiotics relate to environmental impact. This is especially severe in the context of pollutants, since many of which are substances foreign to a biological system that did not exist in nature before their synthesis by humans. Consequently, the toxins specific to slag and ash deposits through the environmental xenobiotics induce malignant tumors of high incidence rate. Within the framework of sustainable development the environmental and technical issues should be linked. In line with this idea it is important to build mathematical models that reflect how the transfer into the subsoil of a toxic dose from a slag and ash deposit source on ground is realized. Identification of such a mathematical model to process the data of mass transfer type could allow relevant conclusions on the interaction polluter - geographic area. This paper presents a case study based on the scenario of the transfer of a toxic dose in the subsoil from the slag and ash deposit on the ground of Isalnita thermoelectric power plant located in Oltenia region, Romania. Taking into consideration the spatial distribution of soil structure in depth it is analyzed the toxic mass transfer into the subsoil based on two scenarios, namely the linear and nonlinear distribution of mass transfer. Based on linear and, respectively nonlinear mathematical models there are performed numerical simulations of toxic mass transfer into the subsoil.

Key-Words: environmental xenobiotics, mass transfer, mathematical model, slag and ash deposit, toxic

1 Introduction

On a broader front the subsoil pollution is caused either by the contamination with saline waters, gases and hydrocarbons, or because of mining and drilling processes [1-3].

It is broadly known that besides oil and natural gas, coal belongs to the group of main energy sources of the 20th and the beginning of the 21st century [1-8]. Further one could note that when it comes to coal there are two main problems: resources are limited and its utilization pollutes the environment. Operation of coal-based power plants determines a big amount of slag and ash, and also releases harmful flue gases. Consequently it is widely accepted that over time the coal-fired power plants operation determined a hard depletion and destruction of our natural environment [1-8]. Accordingly, a serious concern is related to the health of humans and other life forms that is impacted of burning coal in electrical generating stations.

Following this worrying assertion, one could note that slag and ash deposits have a varied and complex impact on groundwater and surface waters, depending on the nature and concentration of pollutant substances [1-8]. Consequently these waters suffered alterations of physical, chemical and biological parameters.

When these changes exceed the limits established by the environment regulations and persist for longer then we have to do with pollution.

Studies have highlighted [3-8] that usually pollutant trace elements in coal, coal ashes and combustion waste have concentrations that exceed the limits imposed by international legislation. Such elements with big values have been shown to be Rb, Cs, Ba, Cu, Sb, Bi, U and Ag [5]. In a decreasing order of significance the trace elements in coal and coal burning waste might occur as organic compounds, impurity components in inorganic amorphous matter, elements in fluid constituents. Trace elements could also occur in water soluble forms, as are Li, Sr, Mo, Cs, Cr, Mn, As, Bi, B, Cl, Br, I, [5] which are contaminating the surface and subsoil waters.

Over the last several decades, the term xenobiotic has become increasingly accepted as relating to environmental impact [8]. Environmental xenobiotics are substances foreign to a biological system, which did not exist in nature before their synthesis by humans. In this context, xenobiotics are persistent pollutants, and dangerous and unstable situations can result from the presence of environmental xenobiotics since their harmful effects on humans and ecosystems are often unpredictable [8-15].

Environmental xenobiotics are becoming increasingly problematic in medicine and environmental systems, since they are relatively new substances and difficult to categorize, and since it is challenging to assess their effects on human health and the environment [8-15].

Coal-fired power plants emit particulate matter, SO_2, NO_x as well as gases that undergo chemical reactions to form fine particles in atmosphere [3-12]. These reactive chemicals (particulate matter, sulfur dioxide and nitrogen oxides) represent environmental xenobiotics, which spread over hundreds to thousands of kilometers downwind of power plants. In addition to the environmental harm caused by greenhouse gases and other emissions, the air emissions of coal-fired power stations encompass a certain amount of toxic xenobiotics that result in significant numbers of human deaths and diseases [8-15]. As a consequence, the pollutant load from environmental xenobiotics concerns researchers in medical and environmental fields.

The immune system is extremely vulnerable and sensitive to modulation by environmental xenobitics [15]. Various experimental assays can be performed to ascertain the immunotoxic potential of environmental xenobiotics, accounting for genetic factors, xenobiotic penetration route, and amount and duration of exposure, as well as the xenobiotic wave shape [8-15].

Through exposure to environmental xenobiotics, people can experience heart disease, respiratory illness and lung cancer, as well as such other health problems as adverse reproductive outcomes, infant death, chronic bronchitis, asthma, and other lung diseases [8-15].

Environmental factors are altered by the slag and ash deposits through environmental xenobiotics which could impact devastating effects on living organisms, including humans. The impact on people is seen by the high incidence rate of primary malignant tumors localized in the central nervous system (malignant glioma) [12-16].

Standard therapy for glioblastoma multiforme (GB) is consisting of rejection surgery, radiotherapy and chemotherapy. Prognosis in patients with GB is reserved [17].

The innovative immunotherapeutic treatment of dendritic cells had not a significantly different effect compared to the treatment of bevacizumab and irinotecan based on the gain in survival [18-19]. GB aggressiveness can be determined by identifying resistance in vitro cell lines GB to a series of inhibitors used in cytotoxic chemotherapy [16-20]. In vitro process can directly reveal cell proliferation, on cell lines GB [17-20].

In this paper, we propose an approach for the analysis of mass transfer of slag and ash sludge xenobiotics into the subsoil using mathematical models.

Mass transfer systems can be estimated on mathematical models that allow a high degree of generality. The mathematical models are expressed by algebraic equations, differential or logical, their form depending essentially on the real system. The mathematical models that describe the behaviour of a system represent the basis of analysis and synthesis of real systems.

2 Case Study. Slag and Ash Deposit of Thermoeletric Power Plant of Isalnita, Romania

The thermoelectric power plant Isalnita is positioned near Craiova. The group of coal-based power plants Isalnita is based on two thermoelectric units of 315 MW at Işalniţa branch.

A thermoelectric unit is composed of two boilers Benson 510T / h, a condensing turbine Rateau-Schneider and an electric generator ALSTHOM of 300MW (see Figure 1).

Fig.1 Thermoelectric unit

Slag and ash deposit is located in a relatively secluded area but can be a potential danger of pollution of groundwater and surface water, including river Jiu (see Figure 2).

Fig.2 Slag and ash deposit of Isalnita power plant/Sludge of slag and ash

2.1 Working Method. First Scenario: Linear Mass Transfer in Soil

The case study is based, according to the first scenario, on the transfer of a toxic dose in the subsoil from a slag and ash deposit on the ground (see Figs. 2 and 3).

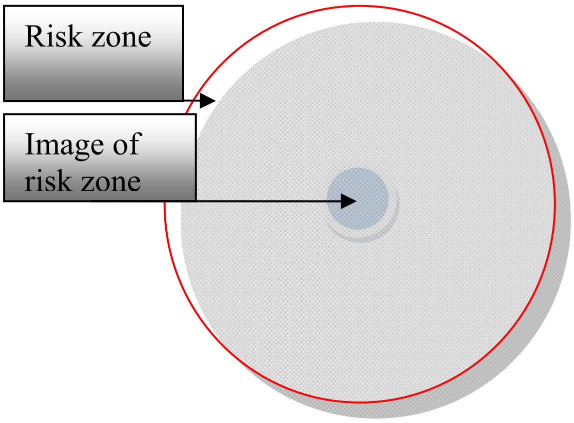

Fig. 3 Positioning Risk Zone Image/ Risk Zone

This type of analysis of soil depth is specific to Oltenia region of Romania.

In each of these situations, specified materials show a different pollutant drag under continuous gravitational effect.

To obtain a simplification of the model, we work with an average of toxic drag.

At first insight, based on the analysis of Fig. 4, it would seem that it is sufficient to determine the linear distance between the point of infiltration of toxic and the point measurement in soil depth.

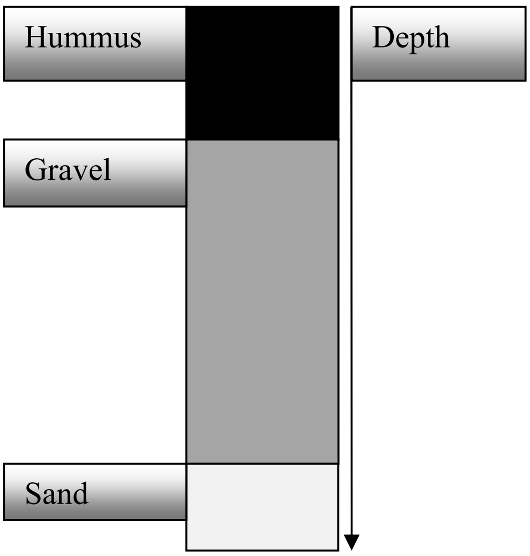

Fig.4 Spatial distribution of soil structure in depth

By working on a simplifying assumption one consider that the toxic distribution in depth into the soil is linear. In this case the mathematical model of D dose distribution in depth, relative to the initial dose D_0 of contact with the pollutant at ground surface is linear, according to the following relation:

$$D = D_0 - x(D_0 - D_A)/x_A \qquad (1)$$

where: D is the current toxic dose at depth x;
D_0 is the initial dose at contact surface;
D_A is the maximum acceptable dose (corresponding to the depth x_A).

In relative units the expression of the pattern becomes:

$$d = 1 - x(1 - D_A/D_0)/x_A \qquad (2)$$

where d is the current relative dose at the depth x.

In order to perform the simulation we used a specific tool to data analysis namely the StatSoft 701. It runs well on a platform based on Intel i3 generation. How to work with this utility requires a great experience in the use of such programs on modern PC platforms running under Windows 8.

In Fig. 5, 6 and 7 there are represented on ordinate the relative values of toxic dose depending on the depth values x represented on abscissa for linear distribution.

According to Fig. 5 on the surface of contact ($x=0$) the toxic dose value is $D = D_0$. Relative dose decreases linearly with the depth x. At the depth x_A = 50 the value of mass transfer is D_A/D_0=0.4.

According to Fig. 6 on the surface of contact ($x=0$) the toxic dose value is $D = D_0$. Relative dose decreases linearly with the depth x. At the depth x_A = 50 the value of mass transfer is D_A/D_0=0.2.

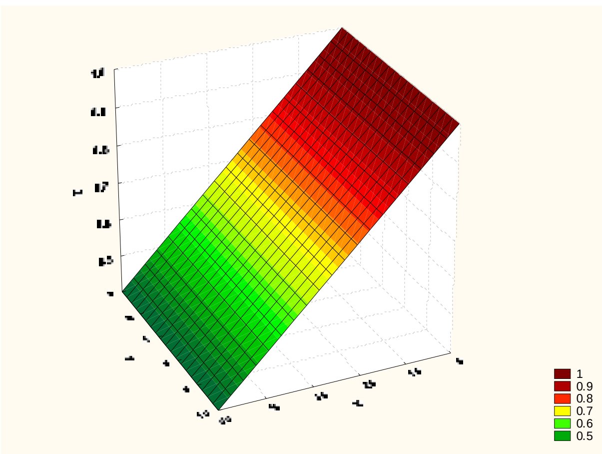

Fig.5 Linear distribution of mass transfer at D_A/D_0=0.4; x_A=50

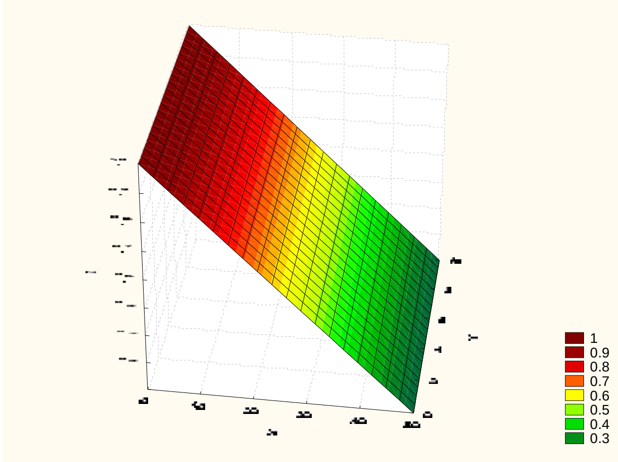

Fig.6 Linear distribution of mass transfer at D_A/D_0=0.2; x_A=50

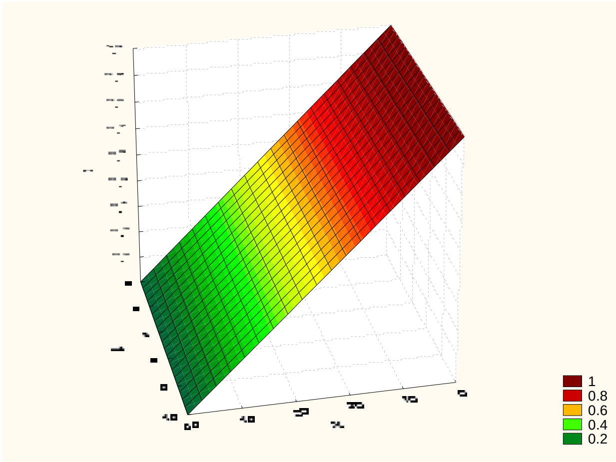

Fig.7 Linear distribution of mass transfer at D_A/D_0=0.1; x_A=50

According to Fig. 7 on the surface of contact ($x=0$) the toxic dose value is $D = D_0$. Relative dose decreases linearly with the depth x. At the depth x_A = 50 the value of mass transfer is D_A/D_0=0.1.

2.2 Working Method. Second Scenario: Non-Linear Mass Transfer in Soil

This case study is also based on a scenario of the transfer of a toxic dose in the subsoil from a deposit source type of slag and ash on the ground (Fig. 2, 3, 4). In this case the materials specified in Fig. 4 shows a different drag of toxic under continuous gravitational effect. Relative to the reference surface, we are dealing with a different route of mass transfer. Based on a nonlinear model described by a nonlinear equation, as below, one could carry out the mathematical modeling and computer simulation:

$$D = D_0 - (D_0 - D_A) \cdot (x/x_A)^2 \qquad (3)$$

In relative units the pattern expression becomes:

$$d = 1 - (1 - D_A / D_0) \cdot (x / x_A)^2 \qquad (4)$$

As previously we run with the tool StatSoft 701 which is specific to data analysis.

In Figures 8, 9 and 10 there are represented on ordinate the relative values of toxic dose depending on the depth values x represented on abscissa for nonlinear distribution.

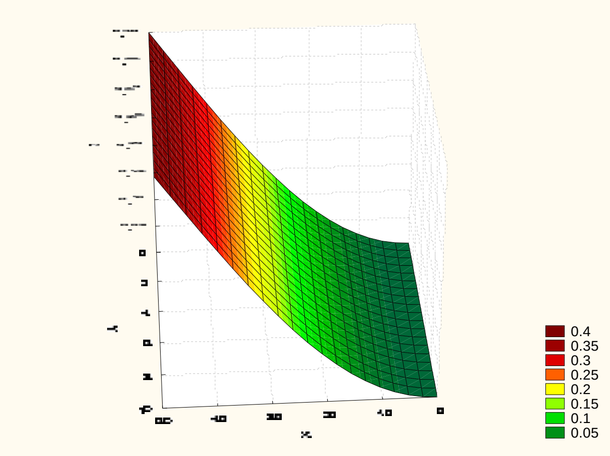

Fig.8 Nonlinear distribution of mass transfer at D_A/D_0=0.4; x_A=50

According to Fig.8 on the surface of contact (*x=0*) the toxic dose value is D = D_0. Relative dose decreases non-linear with the depth *x*. At the depth x_A = 50 the value of mass transfer is D_A/D_0=0.4.

According to Fig.9 on the surface of contact (*x=0*) the toxic dose value is D = D_0. Relative dose decreases non-linear with the depth *x*. At the depth x_A = 50 the value of mass transfer is D_A/D_0=0.2.

According to Fig.10 on the surface of contact (*x=0*) the toxic dose value is D = D_0. Relative dose decreases non-linear with the depth *x*. At the depth x_A = 50 the value of mass transfer is D_A/D_0=0.1.

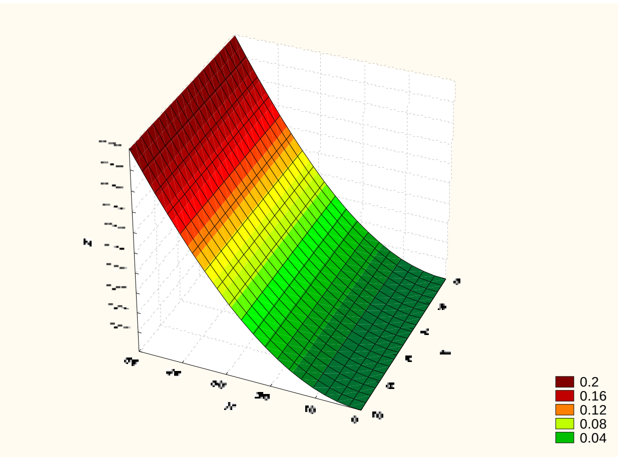

Fig.9 Nonlinear distribution of mass transfer at D_A/D_0=0.2; x_A=50

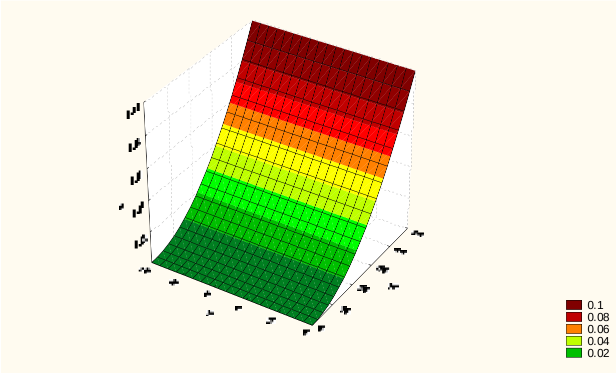

Fig.10 Nonlinear distribution of mass transfer at D_A/D_0=0.1; x_A=50

3 Discussion and Conclusions

Deposits of slag and ash produced by coal-fired power plants induce in living organisms, including the humans the specific environmental xenobiotics. As a consequence this impact is leading to a high incidence rate of malignant tumours.

It is important to identify specific mathematical models with a polluter environmental contamination in a well defined geographical area.

For deposits of slag and ash, defining mass transfer of a toxic dose in the subsoil can be done by identifying / building of a specific mathematical model. A mathematical pattern of mass transfer permits a dimensional calibration of slag and ash deposits. Linear mathematical model may be imposed for relatively small-scale work. For large-scale work is needed the transition to nonlinear mathematical models that can be described by differential equations.

Mathematical modeling is just a milestone to be followed by the numerical simulation of specific phenomena.

The case study carried out in this paper is based on the scenario of the transfer of a toxic dose in the subsoil from the slag and ash deposit on the ground of Isalnita power plant located in Oltenia region, Romania. Taking into consideration the spatial distribution of soil structure in depth it is analyzed the toxic mass transfer into the subsoil based on two scenarios, namely the linear and nonlinear distribution of mass transfer. Based on linear and, respectively nonlinear mathematical models there are performed numerical simulations of toxic mass transfer into the subsoil.

This study aims to emphasize that working within the framework of sustainable development the environmental and technical issues can and should be linked. The operation of coal-fired electric generation stations is impacting all environmental factors, and future needs for sustainable development are likely to include a change in approaching the industrial metabolism concerns, by taking into consideration the interactions between humans applications and the Nature.

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