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THE SOFTWARE SYSTEM FOR MODELLING GAS-DYNAMIC PARAMETERS OF THE OPENCAST ATMOSPHERE

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The local meteorological elements are connected with technical, economic and social parameters of the opencast atmosphere. The goal of this paper is the realization of methods and the developing of software for the calculation and visualization of the distribution of contaminations in the quarry atmosphere based on a simulation study for the dynamics of moving air masses in the opencast space. The environmental impact of mining dust spreading on the concentration of pollutants has been described. Quarry aerology for open-pit mines exploits applications of the theory of functions of complex variables for computing concentration of harmful substances and convective airflows in the local space. The software system for calculation of gas-dynamic parameters in the opencast atmosphere has been developed in the Delphi environment and tested at the calculation of natural ventilation in open-pit mine. The usage of a single vortex method allows creating effective design models, which possess a withstandability of systems of the algebraic equations to define the air-stream velocity in magnitude and in direction at any point of the mine. The algorithm of this method is modified for a task of the simulation study of the mine's space. The problem solution was made on the basis of the mine's designed profiles for 2010 and 2015 built with taking into account prevailing directions of the wind (North, South, West, East). After the velocity field calculation on the basis of the preset information about the location of harmful condition sources is computed the concentration pattern of harmful conditions. By the results of calculations for such fields, by the interpolation of values between the mine's profiles, as a whole, is determined the condition of contamination in the opencast atmosphere. Calculating data on harmful substances distribution in the local atmosphere have allowed determining the contours and volumes of zones in the quarry. The developed program and methodical complex allows performing on-line computation for hydrodynamical fields, and simulating on their basis a change in powder-gas conditions in the opencast. At that the development of mining operations is considered, as well as the evaluation and prediction the condition of air contamination in the environment atmosphere at the area of operations of the works. The results of calculations may be used for creation an ecological GIS of the mining-and-processing integrated works and for the designing a forced ventilation of mines. The further development of this project is the creation of an intellectual system for decision-making in real time, so that to reveal and neutralize the dangerous areas in respect of the factor powder-gas at workplaces in deep opencasts.

Introduction

Up to 80% of the total industrial emissions in the southeast part of Ukraine are connected with enterprises of mining-metallurgical complex. For example, in Dnepropetrovsk region the concentration of mining and metallurgical production is 7-10 times the national average. Production and processing of iron ore is 86% of the national total, cast iron production is 50%, and the production of steel is 47% of the national total. There are several industrial zones in the Pridneprovsky Region:

A) Dnepropetrovsky zone including Dneprodzerzhinsk, Dnepropetrovsk and Novomoskovsk. This industrial zone area is about 1164 km^2.
B) Krivoyrozhsky zone including Shirokovsky, Krivorozhsky, Pyatikhatsky districts with area about 2660 km^2.
C) Manganese ore mining zone including Ordzhonikidze, Marganets, Nikopol. This industrial zone area is about 312 km^2.
D) Western Donbass industrial Zone including Pavlograd and Yurievsky Districts. This industrial zone area is about 1195 km^2.

Especially high volumes of emissions were recorded in the cites of Kryvyi Rig (10.1%), Mariupol (7.8%), Donetsk (5.0%), Zaporizhzhia (3.3%), Dneprodzerzhynsk (2.9%), Enakiyeve (2.6%), Dnepropetrovsk and Alchevsk (2.4%), Lugansk (2.3%), and Debaltseve (2.2%) [1]. The high concentration of the industries in large cities aggravated the very negative impact on natural ecosystems and human health [2, 3]. In the total air pollution Dnepropetrovsk Region holds one of the first places in Europe.

The annual average emission of industrial dust was 1.25 million tons for Krivoy Rog, and 1 million tons each for Dnipropetrovsk, Dniprodzerzhinsk, Nikopol and Novomoskovsk. The amount and the type of emissions in different places of the Dnepropetrovsk region depend on the type of industrial enterprises involved. It is known, iron ore mining-metallurgy in Krivbass results in high levels of industrial dust, sulphur oxides, carbon and nitrogen [4].

The first studies of the microclimate of quarries in Ukraine were made in 1972-1979, when the depth of the iron ore quarries reached 200m. Last time this depth continuously grew and will exceed 400 in the near future. It was established that a number of previous data could not be used for the quarries with depth more than 350m. The meteorological elements are connected with technical, economic and social parameters of the quarry. For example, the low temperatures reduce labor productivity and increase the frequency of occupational diseases among the workers. The calm or weak wind activity leads to an increase of the pollution level in the atmosphere of the quarry; icy grounds and the fog reduce the productivity and can cause quarry accidents. Means for controlling microclimate in the quarry and methods of measuring atmospheric parameters and parameters of the process of origin and formation of dust-gas clouds include telemechanical control of meteorological parameters in an atmospheric framework with application lidars for the laser sounding of the quarry atmosphere, a laboratory and station for remote sensing, etc.

Mitigation approaches to decrease the dust-gas clouds spreading after numerous explosions in the quarries are the following: arranged and technological actions, the explosion zone irrigation, foam application, artificial quarry ventilation.

The goal of this paper is the realization of methods and the developing of software for the calculation and visualization of the distribution of contaminations in the opencast atmosphere based on a simulation study for the dynamics of moving air masses in space.

Aerology of the quarries

The aerology of quarries [5], as a component of environmental protection of the area of mining should promote the production process of required quantity of useful minerals without environmental degradation and natural ecosystems infringement, create comfortable working conditions for the miners, and provide safe living conditions for populations in residential areas. Let us consider aspects of the aerology of quarries in the framework of the following system: "quarry – environment – human." The study of aerology of quarries, revealing the essence and variety of environmental problems and the relationship between separate parts of the system is a complicated matter. Consider a

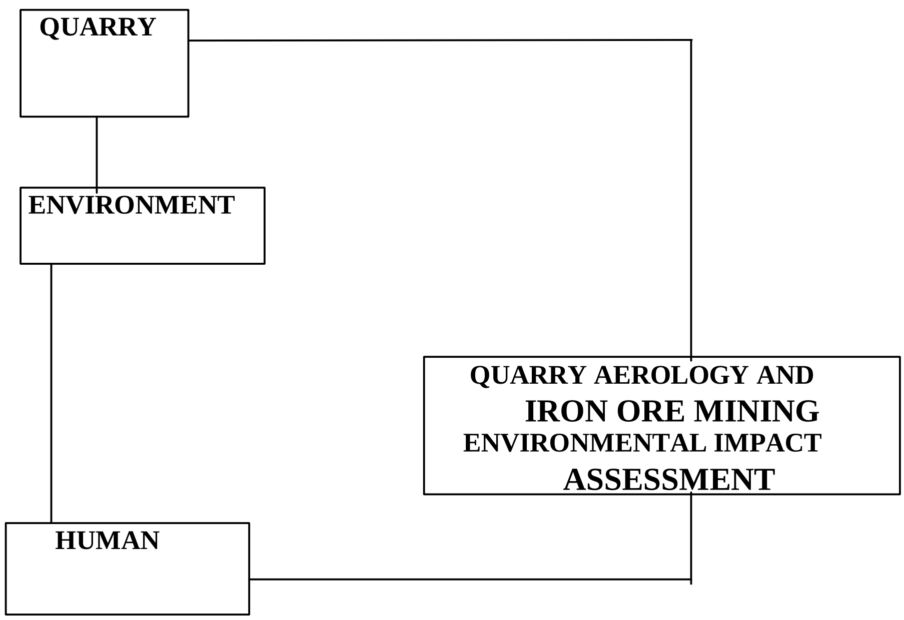

Fig. 1. Scheme of relationships of different aspects of quarry aerology in the framework of "quarry – environment – human" system

brief example of it in figure 1.

There are multilateral, complex, and nonlinear connections between the air circulation parameters of the quarry's atmosphere and environment as a whole, between microclimate characteristics, geothermal and radiating parameters, and between the ecological and social characteristics of the investigated process. In this sense, the system: "quarry – environment – human" can be considered a distributed system. All the relations that take place between separate parts of this system are complex, changeable in time, and have a set of various constants in the equations describing quantitative characteristics of exchangeable processes. For this reason, when studying such a distributed system, it is usually inconvenient to separate the numerous phenomena of radiating, thermal, aerodynamic, geothermal, technical, ecological and social character, as they are closely bound among themselves and are diverse in nature, physical essence, and scale. It is possible to consider three approaches to overcome these difficulties.

The physical approach assumes the description of a complete picture of the aerology of quarries by the analysis of the physical laws controlling the separate processes and their set in the system. Such an approach allows for better understanding/ and better description of the processes involved; It gives mathematical interpretation, and to establishes some quantitative laws. Unfortunately this approach is often hard to use because of the complexity of the "quarry – environment – human" system, and can only be used to study the simplest processes of the aerology of quarries separately.

The heuristic approach establishes empirical connections by logical reasoning, usually, utilizing the results of statistical analysis of the large quantity of numerical information characterizing various processes of the system “quarry – environment – human” under various factors. Due to the distributed character of the system “quarry – environment – human,” the heuristic approach enables the use of various methods of mathematical statistics to establish regression equations connecting the characteristics of the investigated processes with the parameters that form them. In many cases, such as: “quarry radiating balance – humidity,” “wind speed and environment temperature,” “humidity, wind speed and environment temperature,” “humidity, wind speed and environment temperature – atmosphere dust pollution – frequency of occupational diseases, ” or the more complex variant: “blasting mining works – geological conditions – atmosphere microclimate parameters – ecological damage” regression equations can be established. The regression equations contain a large number of parameters. Obtaining these regression equations requires a large number of samples, which makes this heuristic approach impractical.

The combined approach represents a combination of the physical and the heuristic approaches. From our point of view it is the most acceptable approach for studying a “quarry – environment – human” system. The combined approach requires some research in establishing differential equations, each of which serves for the description of the separate parts of the investigated phenomenon or process. The definition of constants in the equations is carried out by statistical analysis of information characterizing relationships between some problem aspects of quarry aerology and the primary complex of parameters.

Modeling of the natural quarry ventilation dynamic schemes with the method of conform reflections include several approaches:

- The straight flowing scheme for air circulation estimation in the quarry with simple configuration contour;
- The straight flowing scheme for air circulation estimation in the quarry with arbitrary configuration contour;
- The recirculation scheme for quarry ventilation estimation.

Thus, quarry aerology for open-pit mines exploits applications of the theory of functions of complex variables for computing concentration of harmful substances and convective airflows in the quarries.

Iron ore blasting impact assessment

More than 40% of iron ore, which is extracted in NIS countries by incurring explosions during open mining projects, is taken from the quarries of the Krivbass. Annually, at Krivbass mining enterprises up to 250 mass explosions with a charge of 600-800 (sometimes up to 1200) tons are set off simultaneously on 15 ledges. After a mass explosion, nitrogen oxide remains in the atmosphere for up to one hour and up to 6 hours within the mass of detonated rock.
There are five iron ore mining enterprises within Shirokovsky and Krivorozhsky districts. There are 200 open-pit mines here as well. The area of the each quarry reaches 3km2. One open-pit mines image is shown as example (Figure 2).

The process of origin and formation of dust-gas cloud (DGC) during the operation of explosives in quarries is a complex, powerfully fusty and flowing process. At birth DGC represents an ordinary object, with a high - density space and temperatures having a large stock kinetic and thermal energy, which has insignificant geometrical parameters (up to several hundred м^3). At the development stage, DGC represents an object with a polydisperse (dust-gas air) space having an insignificant density and temperature equal to ambient temperatures. In its final stage of development, DGC has significant geometrical parameters (from several hundred thousand up to ten million м^3). DGC’s powerful potential represents the sum of dynamic and thermal potentials produced by the explosive energy. Data from more than twenty videos of the mass explosions were taken into account while studying the formation process of a DGC.
The maximum volume of simultaneously blasted explosive substance (ES) within one quarry in the Krivbass iron ore mining region is about 1000tons. 63-80% of the dust-gas cloud particles dropped out around the iron ore quarry had a diameter <1.4mkm as usual. Two types of the dust-gas clouds were determined: primary and secondary. Clouds formation process occurs during 30-45s after blasting. Then intensive dropping of larger dust fractions from cloud takes place within 60-120s. It was established that blasting gases and a lot of small particles spread at long distances (up to 10000-12000m) depending on wind velocity [6].

The impact of mining dust spreading on the concentration of metals as well as the biological activity of the soil (invertase, phosphotase and urease enzymes) has been studied at a distance of 0,5-1,5, 3-5, 5-7 and 10-12 km from the mining site to the north of Krivoy Rog [4, 6]. The overall goal of the integrated approach was development of a generally applicable tool for evaluation of polluted areas based on contaminants toxicity, soil resistance, efficiency of remediation cost as well as on legal aspects of land use, in order to establish priorities for soil remediation practices. The tool was developed as multi-layer map for the polluted areas assessment [7]. It was established also that long - term pollution of soil by quarry dust led to violation of its biochemical status.

Thus the nowadays at working, reconstructed and newly created mines one of the important items is the providing the normal atmosphere, which meets the requirements of public health regulations and guarantees a safe and high-efficiency operation. The underestimation of the atmospheric condition effect, developing in the opencast leads to significant economic losses and influences negatively miners’ health.

The major factors determining the form of pollution for the atmosphere of opencasts are velocity fields, a source of detrimental impurities evolution, its strength and the distribution of the sources on the opencast area. A design study of abilities for a natural ventilation includes: calculations of the velocity fields in the opencast at various wind directions, the determination of volumes in recirculation zones, the calculation of total intensity of the harmful conditions evolution, as well as the calculation of harmful conditions concentration in the opencast atmosphere, and the necessity to use a method for a forced ventilation.

Taking into account the complexity to solve spatial problems of the dissipation of pollution in the opencast, due to the terrain feature and the large volume of the processed information, it is necessary a sharing use of GIS-technologies (Geographical Information Systems). It is also desirable to use such numerical methods, as a complex approach to the solving of problems connected with an environmental monitoring of the atmosphere in the whole mining area. There arises a social order to create a software system of complexes for the calculation gas-dynamic parameters of the atmosphere in opencasts. This order coincides with the goals of the «Guidelines of the State Policy on Protection of the Natural Environment» (1998) and with the «Concept of Improvement of Ecological Condition in Mining Regions of Ukraine», approved by the Cabinet of Ukraine in August 1999.

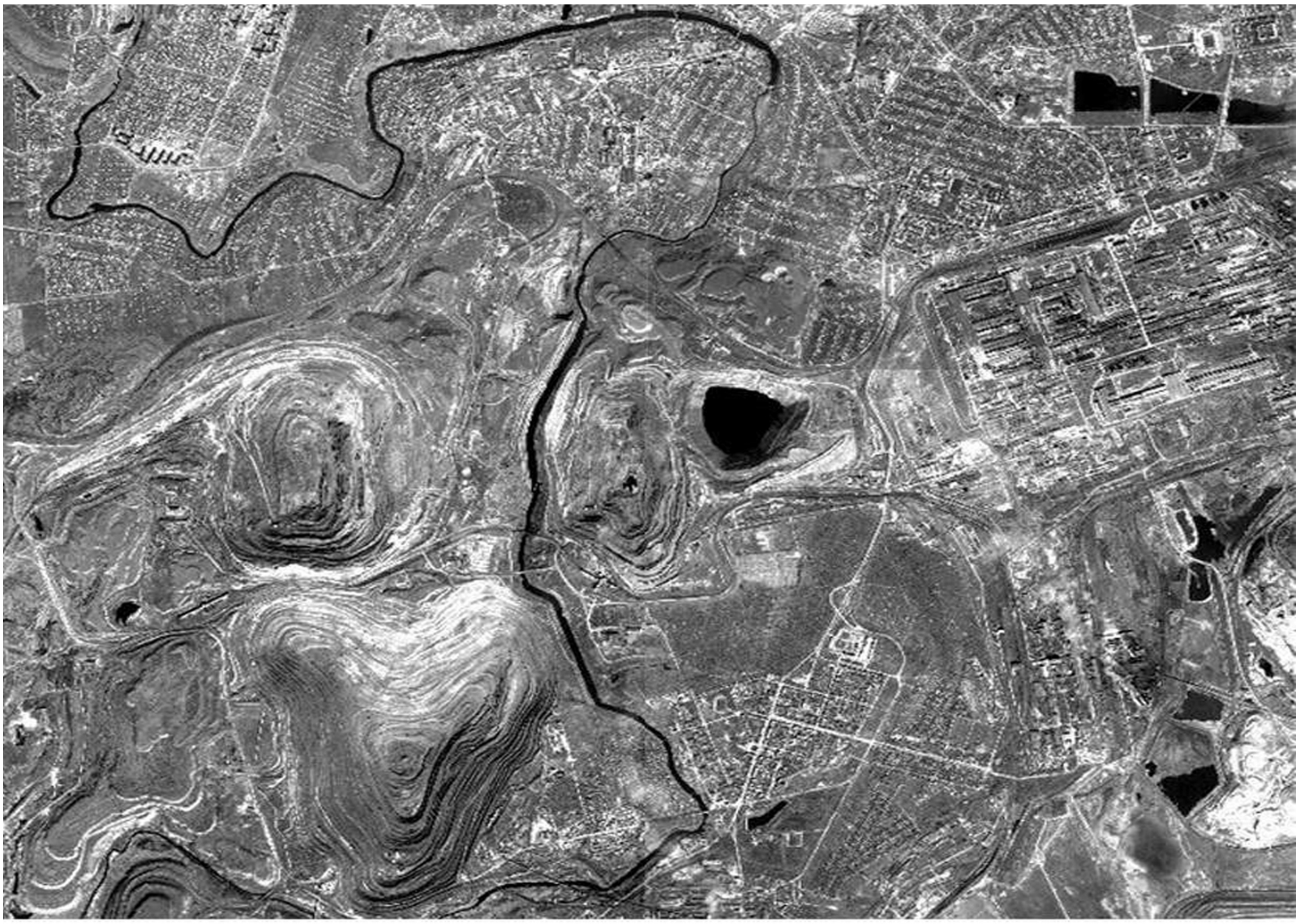

Fig. 2. Open-pit mines image.

To limit the pollutant emissions Ukraine needs to develop environment legislation, environmental impact assessment procedures, and networks of monitoring locations to provide good environment monitoring and auditing for enterprises. It is necessary to implement new mitigation measures: to decrease the general levels of industrial air pollutants, etc.

Pre-requisites for creating effective design models

Prospects for the bi - dimensional mathematical models of the quarry natural ventilation processes were considered. Bi-dimensional non-stationary mixed convection was considered for the turbulent liquid in “trench” with curvilinear section. The model includes the famous Navier & Stokes, heat conduction and diffusion equations. Besides, the additional equation of heat transfer was involved. The buoyancy force in the hydrodynamic equation was taken into account as well. The system of differential equations for solving the task of free thermal convection in the quarry was treated numerically. The developed programs were used for the current estimation of the circuits of quarries ventilation to define the levels of pollution to develop the forthcoming practical recommendations [8].

The usage of a single vortex method allows creating effective design models, which possess a withstandability of systems of the algebraic equations to define the air-stream velocity in magnitude and in direction at any point of the mine [9]. The algorithm of this method is modified for a task of the simulation study of the mine’s space [10]. Let us consider the process of carrying contaminations in the air. In case of a two-dimensional statement of problem the differential equation for a travel of polluting substances is as follows:

$$\frac{\partial\varphi}{\partial t}+\frac{\partial(u\varphi)}{\partial x}+\frac{\partial(v\varphi)}{\partial y}+\sigma\varphi=$$
$$=\frac{\partial}{\partial x}\left(\mu_x\frac{\partial\varphi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_y\frac{\partial\varphi}{\partial y}\right)+\sum_{i=1}^{N}q_i(t)\delta(\bar{r}-\bar{r}_i(t))$$

Where φ is the concentration of a polluting substance in the unit of volume; (for gas and aerosol contaminants);

v - air velocity (a contaminant gas or aerosol);

σ - disintegration constant of contamination (of chemical decomposition, neutralization, washout);

μ_x, μ_y - factors of the turbulent diffusion;

q_i - intensity of point sources of contamination, which can be a function given at random from time;

$r_i = (x_i, y_i)$ - coordinates of the point sources location (sources can move, and that is considered by dependence $r_i(t)$);

δ - Dirac delta function.

As a numeric scheme of the equation integrating is chosen a four-step alternately triangle difference scheme [11], which is an absolutely stable and tacit difference scheme.

The software system of the calculation for distribution of contaminations in the opencast atmosphere

The software system of the calculation for distribution of contaminations in the opencast atmosphere consists of the following modules:

a) Basic modules:

1) Main Unit – it is the major module of the program interface;
2) Geometry - the module realizing the modelling algorithm for the airflow by a single vortex method;
3) Speed Field Class – the realization of a category for build-up and processing the field of velocities;
4) Concentration - the module of calculation for a concentration pattern;
5) Open Pit - the control module for projects

b) Additional modules:

1) Matrix - the module for processing the matrix data;
2) Scale - the operation module with various systems of axes;
3) List - the operation module with structures of type "list";
4) Service - the module with different service functions;
5) Open Profile Dialog - the module of a dialogue box of profile opening;
6) Profile Props Dialog Unit - the module of a dialogue box of profile properties;
7) Schedule Unit - the module of a dialogue box "Scheduler";
8) Speed Field - the module of a dialogue box with parameters of a velocity field;
9) View Settings Unit - the module of a dialogue box with a profile's settings display;
10) Borders - the module of a dialogue box «Borders and dimensions»;
11) Calc. Profile Dialog Unit - the module of a dialogue box of parameters for calculation of a profile;
12) Go Params Unit - the module of a dialogue box for modelling parameters;
13) Harm Cell Unit - the module of a dialogue box for editing of sources with harmful conditions.

Images saving blocks and the making of reports are found in the Main Unit module and are a part of the program interface.

Below are indicated major categories created for implementation of the above- mentioned abilities.

1) Category TMatrix is used for processing the matrix data. It contains the information of the matrix structure and makes different operations with them (including the location of a reciprocal matrix).

2) Category TSpeedField saves and treats matrixes of a field of velocities, and attaches them topologically to the profile's flat surface.

3) Category TConcentrationField contains the data and methods for calculation of the harmful condition concentration. Category TMatrix is used for the data storage.

4) Category TGeometry stores all the initial and derivative data about a profile, contains the functions fulfilling the modelling of air masses by a single vortex method, encapsulates subjects of all the above described categories and the visualization methods for all produced data.

5) Category TOpenPit - stores and processes the list of subjects like TGeometry, stores and downloads the project's files.

Figure 4 shows the scheme of interaction of objects within the program.

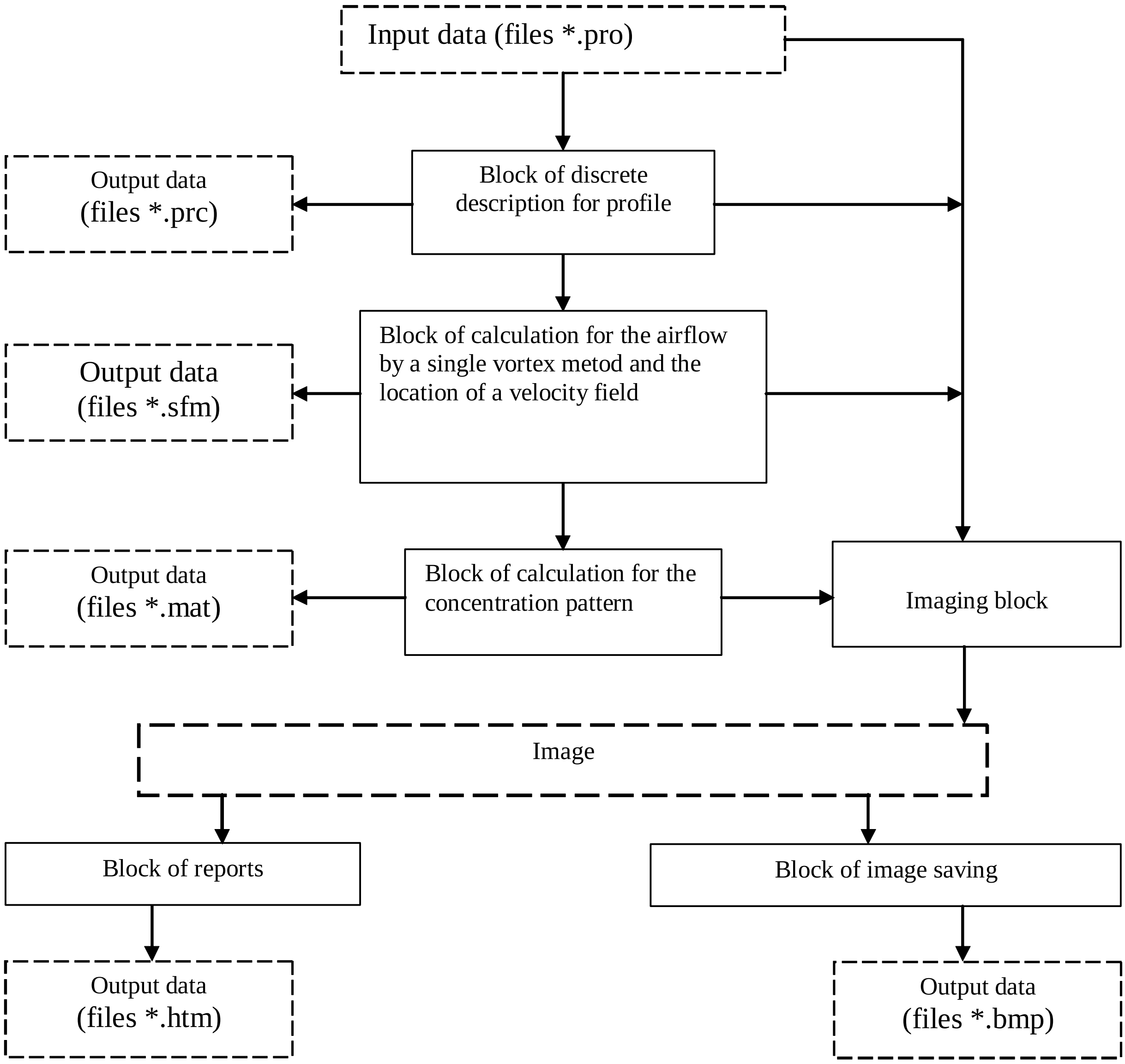

Figure 3. Program's block scheme

The software system for calculation of gas-dynamic parameters in the opencast atmosphere has been developed in the Delphi environment and tested at the calculation of natural ventilation in open-pit mine No.3 NKMPIW (Noviy Krivorozhsky Mining-and-Processing Integrated Works «Krivorozhstal». The problem solution was made on the basis of the mine's designed profiles for 2010 and 2015 built with taking into account prevailing directions of the wind (North, South, West, East).

The major resource-intensive stage is the calculation a field of velocities in the profile in the set direction. The example of the calculation outcome for the field of velocities in the profile is shown in Figure 5.

After the velocity field calculation on the basis of the preset information about the location of harmful condition sources is computed the concentration pattern of harmful conditions. A fragment of such a computation in mine No.3 of NKMPIW is introduced in Figure. 6. By the results of calculations for such fields, by the interpolation of values between the mine's profiles, as a whole, is determined the condition of contamination in the opencast atmosphere.

Calculating data on harmful substances distribution in the local atmosphere have allowed determining the contours and volumes of zones in the quarry. The developed program and methodical complex allows performing on-line computation for hydrodynamical fields, and simulating on their basis a change in powder-gas conditions in the opencast. At that the development of mining operations is considered, as well as the evaluation and prediction the condition of air contamination in the environment atmosphere at the area of operations of the works.

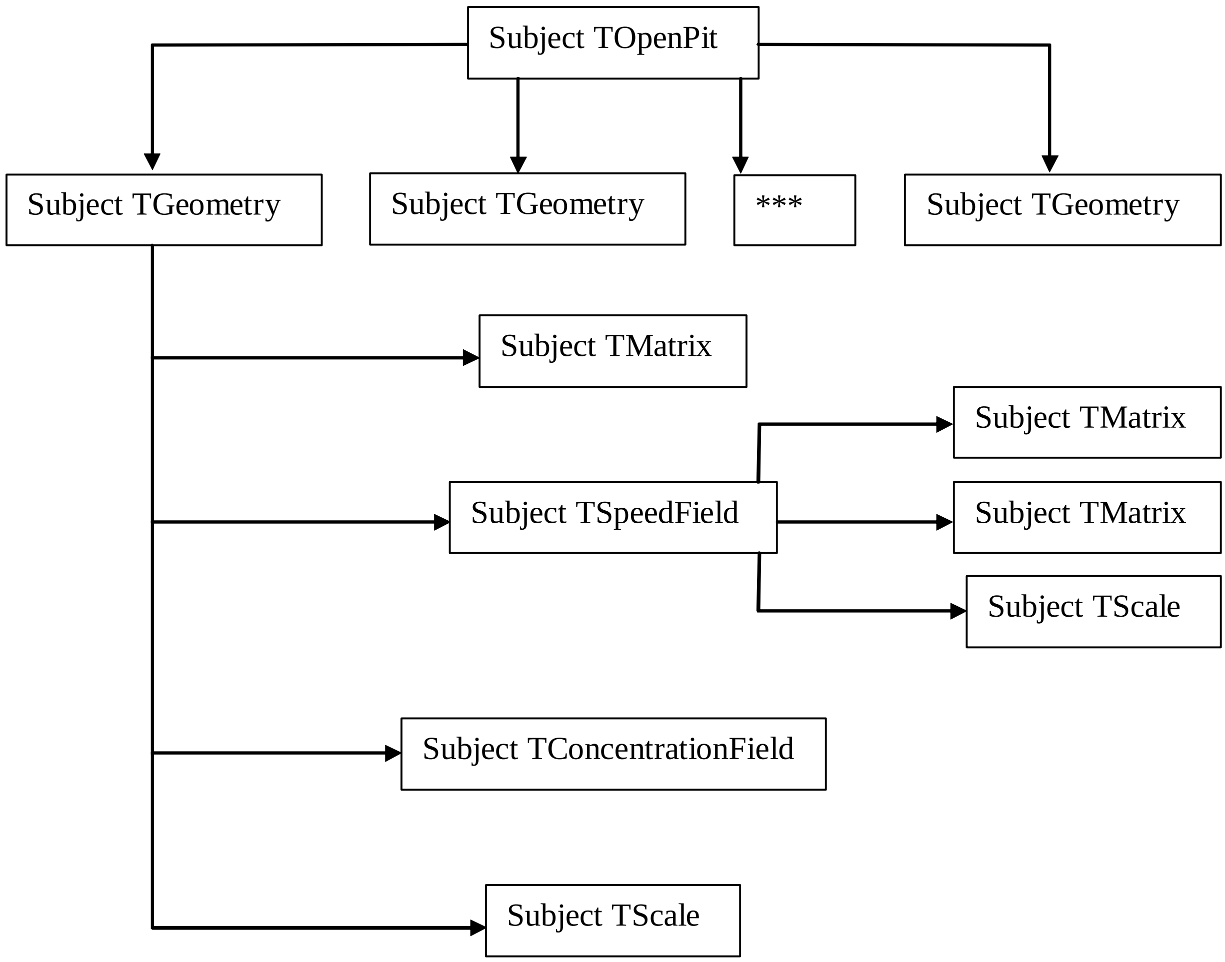

Fig. 4. Diagram of objects interaction.

The results of calculations may be used for creation an ecological GIS (Geographical Information System) of the NKMPIW (Mining-and-Processing Integrated Works) and for the designing a forced ventilation of mines. The further development of this project is the creation of an intellectual system for decision-making in real time, so that to reveal and neutralize the dangerous areas in respect of the factor powder-gas at workplaces in deep opencasts.

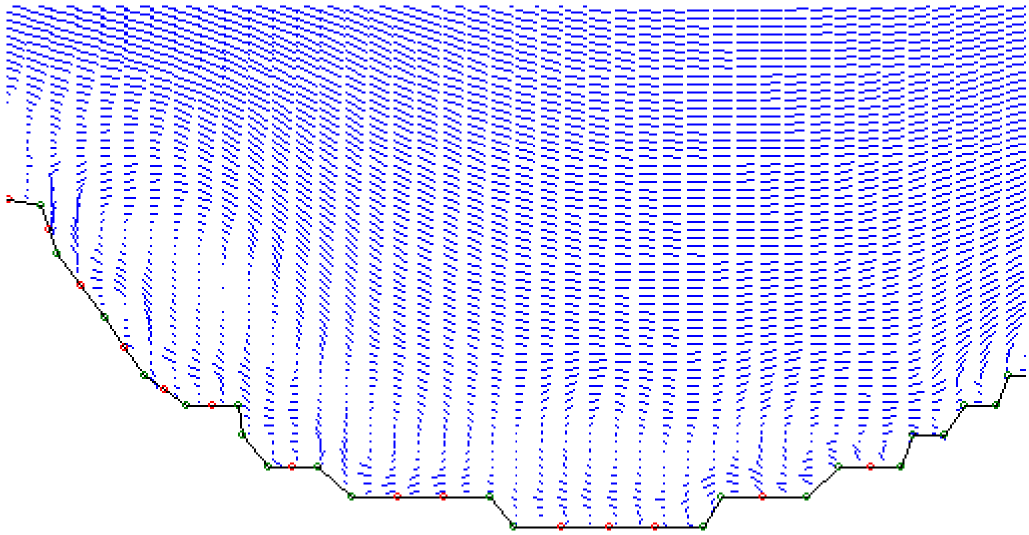

Fig. 5. A velocity field fragment of the profile in opencast No. 3 NKMPIW

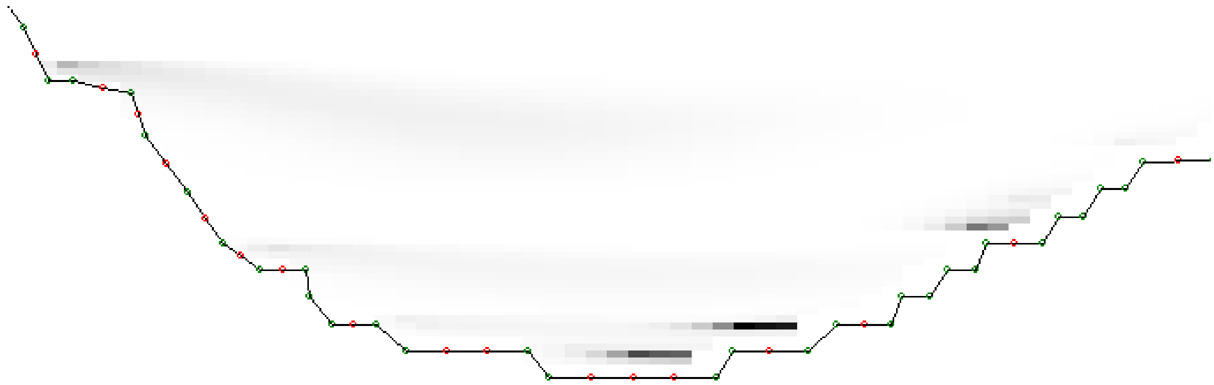

Fig. 6. A concentration pattern fragment of harmful conditions in opencast No. 3 NKMPIW

1. *National report on the environmental conditions in Ukraine for 1998 prepared by the Ministry for Environment Protection and Nuclear Safety of Ukraine* (CD-ROM publication, Web pages created by the Ministry for Environmental Protection and Nuclear Safety of Ukraine, www.grida.no).
2. *National report on environment state in Ukraine,* 1995. (1997). Raevsky Press. Kiev. – 96p.(Ukrainian)
3. *Gritsan N., Babiy A.* Case study. Hazardous materials in the environment of Dnepropetrovsk Region (Ukraine). (2000). Journal of Hazardous Materials, A76: 59-70
4. *Kharytonov M., Gritsan ,N., and Anisimova,L.* Environmental problems connected with air pollution in the industrial regions of Ukraine. In: Global atmospheric change and its impact on regional air quality. Barnes, I. (Ed). NATO Science Series, IV: Earth and environmental sciences. Kluwer Academic Publishers, 2002b; 16: P. 215-222
5. *Zberovsky A.V.* Air protection in the quarry – environment - human system. Dnepropetrovsk, 1997. – 136 p. (in Russian)
6. *Kharytonov M.M., Zberovsky A.V., Drizhenko A.Y.* Blasting impact assessment and mitigation of the dust – gas clouds spreading in the iron ore mining region of Ukraine. NATO ASI on Data Fusion to Situation monitoring, Incident Detection, Alert and response Management, August, 18-29, 2003. CD-ROM
7. *Ruth E., Kharytonov M.* Integrated approach for Assessment of Polluted Areas. In: Social and Environmental Impacts in the North: Methods in evaluation of socio-economic and environmental consequences of mining and energy production in the Arctic and Sub-Arctic. Rasmus Ole Rasmussen and Natalia E. Koroleva (Ed). NATO Science Series, IV: Earth and environmental sciences. Kluwer Academic Publishers, 2003; 31. – P. 57-66
8. *Kharytonov M., Zberovsky A., Drizhenko A.Y. Babiy A.* Air pollution assessment inside and around mining iron ore quarries, Advances in air pollution modeling for environmental security, Edited by Istvan Farago, Krassimir Georgiev, Agnes Havassi, Series IV. Earth and Environmental Series. Vol.54. - 2005.- Springer. Printed in the Netherlands, Published in cooperation with NATO Division. – P. 263-274
9. *Zberovsky A.V., Zadornova V.V., Grigoryev V.B., Goman O.G.* A Single Vortex Method in the System of the GOK Ecological Monitoring // The Collection of Scientific Papers of the National State Academy of Ukraine, No. 12. - Volume. 1. - Dnepropetrovsk: EC NMAU, 2001. – P. 275-280.
10. *Goman O.G., Zberovsky A.V., Zadornova V.V., Dubey V.V., Kozakevich O. P.* An Algorithmic Complex for Calculation a Field of Velocity in the opencast by the Method of Single Vortex.// The Collection of Scientific Papers of the National State Academy of Ukraine, No. 13. - Volume. 1. - Dnepropetrovsk: EC NMAU, 2002. – P. 236-243.
11. *Marchuk G. I.* A Mathematical Simulation Study of the Environment Problem. - Moscow: Science. The Main Editorial staff of Physical and Mathematical Literature, 1982. – P. 320.