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MATHEMATICAL MODELLING OF GAS-DYNAMIC PROCESSES IN THE SURFACE ATMOSPHERIC LAYER OF URBAN TRAFFIC ZONES

MATEMATIČKO MODELIRANJE GAS-DINAMIČKIH PROCESA U POVRŠINSKOM SLOJU ATMOSFERSKOG OMOTAČA GRADSKIH SAOBRAĆAJNIH ZONA

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Abstract: *The modelling of gas-dynamics processes in the air surface of the urban terrains can be made with the application of the GAS DYNAMICS TOOL software. The program is capable to solve wide range of problems with non-stationary flows of non-viscous compressible gases on the basis of the integral equations of the Euler with application of a modified method of final volumes. The Novye-Stokes equations solution algorithm included in the program allows interaction of airflows with bodies, viscous effects in gases and many others ones to be taken into account. The complex evaluation of the atmospheric air can be made on the basis of the results of gas-dynamics transmission admixtures mathematical modelling in the surround atmospheric layer.*

Key words: *modelling of gas-dynamics processes, urban terrains,road network, traffic, urban landscape*

Apstrakt: *Modeliranje gas-dinamičkih procesa u atmosferi gradskih zona može se vršiti pomoću softvera GAS DYNAMICS TOOL. Ovaj program je u stanju da reši niz problema u oblasti nestacionarnog protoka neviskoznih stišljivih gasova koristeći Eulerove integralne jednačine primenom modifikovane metode konačnih zapremina. Program uključuje i algoritam Novi-Stouksove jenačine koji omogućava interakciju vazdušnih strujanja i tela, analizu viskoznih efekata u gasovima i mnoge druge opcije koje treba uzeti u obzir. Slozena analiza i procena atmosferskog vazduha maže se vršiti na osnovu rezultata matematičkog modelitanja gas-dinamičkih transmisija primesa u atmosferskom omotaču.*

ključne reči: *modeliranje gas-dinamičkih procesa, gradske zone, putna mreža, saobraćaj gradska sredina*

1 INTRODUCTION

Urgency of the modelling problem of the gas-dynamics processes in the surface atmospheric layer of the Tula city is stipulated by the increase of negative tendencies in the population health

1 UVOD

Modeliranje gas-dinamičkih procesa u površinskom sloju atmosferskog omotača grada Tule postaje sve neophodnije, s obzirom na to da je uočen negativan uticaj na zdravlje gradske populacije zbog visokog

change, bound with sharp deterioration of the ecological situation in the city. The technogenic pollution of environment represents actual danger refer not only to a health of a single person, but the whole population promoting the development of the specific ecologically dependent pathology. The significance the investigations being carried out are obvious, because the final part of any migration of harmful compounds in components of the environment is Man.

Pollutant emissions into the atmosphere, which grow constantly, are the significant source of the city being polluted. Today the majority of the contaminants entering the atmosphere of the cities is consequences of the transport (over 70 % from of the aggregate emissions in Tula city), their mass will grow with the number of vehicles in the city being increase. Space distribution of the gas atmospheric emissions on the city terrain is rather heterogeneous. So the pollution from stationary sources is of area distribution and explained by the allocation of large enterprises and the "wind rose", and the pollution from transport is of linear character and refers to the city basic highways. The unfavourable situation is aggravated by the fact that the contamination of the environment by transport cannot practically be decreased, the city population is exposed to its action even in residential area.

2 PRINCIPES OF MODEL CONSTRUCTION

The process of transport diffusion in atmosphere takes place at the expense of their advective transmission by air masses and diffusion stipulated by turbulent pulsation of the air. If emissions thrown into the air consist of large particles, they are spread into the atmosphere and are deposited with defined constant speed under the effect of gravitation according to the Stokes law. It is natural, that finely almost all admixtures precipitate on a ground surface, the heavy ones being precipitated basically under the effect of gravitation, while the light ones are precipitated as a result of a diffusion process. The gravitational flow of heavy particles happen to be much greater then the diffusion one, while for light admixtures it is practically insignificant [1]. As heavy metals are most dangerous for the environment, it is to those bonds that the greatest value is given.

Multiple changes of velocity and wind direction are the great significance in the admixing diffusion theory for a defined period of time (day, month, and year). The assessment of the city wind conditions is conducted on the basis of the

stepena ugorženosti životne sredine. Tehnogeni faktor zagađenja predstavlja suštinsku pretnju ne samo po zdravlje pojedinca, već i čitave populacije, pri čemu se javlja specifična vrsta patologije koja je usko povezana sa ekološkim faktorima. Značaj istraživanja koja se sprovode je evidentan, ako se uzme u obzir da je čovek poslednja karika u procesu ugrožavanja životne sredine.

Emisija polutantana, koja je konstantno u porastu, predstavlja bitan izvor zagađenja grada. U današnje vreme najveći deo zgađivača koji dospevaju u atmosferu velikih gradova potiču iz saobraćaja (preko 70% od ukupnih emisija u Tuli), a očekuje se stalni porast s obzirom na sve veći broj automobila. Rasprostiranje emisija u gradskoj zoni je veoma heterogeno. Zagađenje iz stacionarnih izvora je pretežno regionalnog karaktera, što je posledica koncentracije velikih fabrika i ruže vetrova. Zagađenje koje nastaje kao posledica saobraćaja je linearnog karaktera i odnosi se na glavne gradske saobraćajnice. Nepovoljnost leži u činjenici da se zagađenje životne sredine, koje je posledica saobraćaja, ne može praktično nikako umanjiti, te je gradska populacija neprekidno izložena njegovom negativnom uticaju, čak i u stambenim oblastima.

2 PRINCIPI IZRADE MODELA

Rasprostiranje emisija u atmosferi odvija se usled prenosa toplote horizontalnim kretanjem vazdušnih masa i usled vrtložnog treperenja vazduha. Ukoliko se emisije sastoje od krupnih čestica, one se rasprostiru u atmosferi i talože konstantnom brzinom pod uticajem sile gravitacije, a u skladu sa Stouksovim zakonom. U krajnjoj instanci gotovo sve vrste primesa se konačno talože na površini zemlje. Teže čestice se u osnovi talože pod uticajem gravitacije, dok se lakše čestice talože usled difuzionih procesa. Treba napomenuti da je taloženje putem gravitacije daleko intenzivnije od taloženja difuzijom, dok je taloženje lakih primesa praktično zanemarljivo [1]. S obzirom na to da su teški metali najopasniji po životnu sredinu, njima će biti posvećena najveća pažnja.

Stalna promena brzine i pravca vetra je od najvećeg značaja za teoriju difuzije smeša u određenom vremenskom periodu (dan, mesec i godina). Procena karakteristika gradskog vetra vrši se na osnovu ustanovljenih pravilnosti koje nastaju u uslovima gradske sredine.

establishment of the regularities being formed under the influence of the urban landscape elements and its composition as a whole. Correlation of green and built-up areas, direction of streets and road ways, character of the built-up areas, relief and water bodies are in view. The green and built-up areas is the basic regulator of the wind condition. The architectural analysis of the microclimate on separate parts of the city can be carried out for a more exact description of wind conditions. Basic factors calling forth changes of climate conditions in the urban built-up areas are: variation of the thermoexchange in the city due to the horizon being closed and thermophysical properties of urban surfaces; artificial formation of thermal flows during heating and transport functioning; arising of "urban breezes", being formed at the result of the landscape various devices pressure difference and etc [2]. If necessary the input data can be supplemented by special full-scale surveys.

A detailed study of the urban environment (architectural solutions, microclimate, leveling operation...) is conducted according to a topographical maps (the maps of 1:1000, 1:5000, 1:10000 are used). It becomes possible at the use of the "Geographical Information System - Industrial City" program. Modern GIS with their possibility of the data base level organisation play a role of a topographical and information basis on the one hand, and allow receiving the complete many factorial assessment of the urban environment state on the other hand. In that case, the database "GIS - Industrial City" is the basic one in modelling gas-dynamic processes in a surface layer of the air. Mathematical simulation of diffusion transmission of admixtures is one of the major practical methods, the dimensions, geometry and waste distribution specification in built-up arias and industrial territories of the city enterprises having being permitted to be estimated.

An important requirement being expressed to mathematical models is the opportunity to integrate diverse and asynchronous observational data supplementing them with the results of calculations if necessary. The requirements to such models are very high, as the landscape heterogeneity (building, relief, climate, temperature of a surface) influence the transmission and diffusion of the admixtures.

Particular impotent problems arise in connection with information insufficiency concerning exhausts from vehicles. The level of the air pollution is determined by technical parameters and ecological specification of vehicles, type of motor,

Razmatra se uzajamni odnos zelenih površina i izgrađenih zona, pravac prostiranja ulica i puteva, priroda i karakteristike izgrađenih zona, reljef i vodotokovi. Zelene površine i izgrađene zone grada predstavljaju faktore koji presudno utiču na prirodu vetra. Kako bi se što preciznije odredila priroda vetra potrebno je analizirati arhitekturu pojedinih delova grada i odgovarajuću mikroklimu. Osnovni faktori koji utiču na promenu klime u gradskim zonama su promenljiva razmena toplote do koje dolazi zbog zatvorenog horozonta i termofizičkih karakteristika gradskih površina, veštački formirani termalni tokovi koji nastaju usled delovanja grejanja i saobračaja, nastajanje tzv. "gradskog povetarca" kao posledica razlike u pritiscima itd [2]. Ukoliko je to potrebno ulazni podaci mogu se potkrepiti sveobuhvatnim namenskim istraživanjima.

Detaljno istraživanje gradske sredine (arhitektonska rešenja, mikroklima, rušenje, niveliranje itd.) sprovedeno je na osnovu topografskih kartata (korišćene su karte 1:1000, 1:5000, 1:10000). Savremeni GIS program "Geografski Informacioni Sistem" namenjen industrijskim gradovima predstavlja važnu topografsku i informacionu bazu, a s druge strane, omogućava iscrpnu analizu i procenu stanja žiivotne sredine u urbanoj sredini. Baza podataka programa GIS - Industrijski Grad predstavlja osnovu za modeliranje gas-dinamičkih procesa u površinskom sloju atmosferskog omotača. Matematička simulacija difuzione transmisije primesa je jedne od najpraktičnijih metoda, koja omogućava određivanje dimenzija, geometrije i distribuciju otpadnih materija u stambenim, industrijskim i ostalim naseljenim zonama grada.

Matematičko modeliranje pruža još jednu važnu mogućnost, a to je integracija različitih, heterogenih podataka, koji se mogu upotpuniti odgovarajućim proračunima, ukoliko je to potrebno. Ova opcija je veoma značajna, s obzirom na to da gradska sredina ima čitav niz heterogenih karakteristika (građevine, reljef, klima, temperatura tla) koje utiču na difuzionu transmisiiju primesa.

Izuzetno važan problem javlja se usled nedostatka dovoljnog broja podataka u vezi izduvnih gasova iz saobraćaja. Nivo zagađenja vazduha određuje se putem tehničkih parametara i tehničkih karakteristika vozila, vrste motora, karakteristika saobraćaja (struktura, intenzitet i brzina), topografije putne mreže, količine saobraćajnica, kvaliteta puteva,

characteristics of the traffic (composition, intensity and velocity of motion), road network topography, amount of traffic lanes, quality of a road covering, features of traffic light regulation, etc. The development of the carefully balanced and detail program of database is necessary.

Input data at calculating transport exhausts are:

- statistical materials,
- results of modeling the process of environment contamination by power engine of a separate automobile and
- data of full-scale surveys, during which required performances of the surveyed process are fixed directly.

Collecting statistical materials is conducted on the basis of reports on the number and composition of a Vehicles Park, vehicles structure in compliance with fuel consumed, the average age of a Vehicles Park, run of vehicles groups, data about development of transport facilities and others;

The purpose of collecting statistical data is obtaining the information:

- about the development of city transport economy,
- about the change of the number and the composition of the Vehicles Park,
- about the vehicles structure in compliance with the fuel consumed and others.

All the necessary information, for convenience, can be integrated in a specialized database.

The traffic structure can be detailed depending on the chosen version of embodying of procedure. Thus the composition of traffic being the base of the particular city, the data of being oriented which can serve in creating power stations. In cases, when it is difficult to receive the specific data in completely, it is possible to generalize of vehicle types (cars, lories, and buses), or the empirical formulae and statistical evaluations for typical situations can be used.

The data about composition of the Vehicles Park and vehicles structure in compliance with fuel consumed are included into the database. The reliability of evaluating exhausts quantity of pollutants depends, first of all, on the results of statistical sample being thoroughly examined.

The purpose of modeling and development the testing is obtaining information on the fuel being consumed and pollutants of the waste with exhaust

karakteristike svetlosne signalizacije itd. Prema tome, neoophodno je sveobuhvatnu bazu podataka detaljno izraditi i pažljivo izbalansirati.

Ulazni podaci za obračun izduvnih gasova iz saobraćaja su:

- statistički podaci,
- rezultati modeliranja procesa zagađivanja izduvnim gasovima za svaki pojedinačni automobil i
- podaci kompletnih istraživanja, koji su direktno vezani za posmatrane procese.

Prikupljanje statističkih podataka zasniva se na izveštajima o broju i strukturi "voznog parka", odnosno o tipu vozila prema vrsti goriva, prosečnoj starosti, klasifikaciji po grupama, podacima o obnavljanju i unapređenju javnog saobraćaja i sl.

Statistički podaci prikupljaju se radi sticanja uvida u sledeće procese:

- razvoj i organizacija gradskog saobraćaja,
- struktura voznog parka i promene u brojnom stanju,
- klasifikacija voznog parka prema tipu goriva i sl.

Po potrebi u specijalizovanu bazu podataka mogu se ubaciti i druge potrebne informacije.

Organizacija saobraćaja može biti prikazana na različite načine, zavisno od odabrane verzije. U slučaju da nije moguće pribaviti detaljnije informacije, vozila se mogu klasifikovati prema tipu (autmobili, teretna vozila, autobusi) ili se mogu primeniti empirijske formule i statističke analize za tipične situacije.

Baza podataka, takođe, sadrži i informacije o strukturi voznog parka i klasifikaciju prema tipu goriva. Pouzdanost analize i procena emisije polutanata zavisi, prvenstveno, od ispravnosti i tačnosti ispitivanog statističkog uzorka.

Svrha modeliranja i testiranja je pribavljanje informacija o vrsti goriva koje se koristi, polutantima iz otpadnih i izduvnih gasova pojedinačnih vozila prema proizvođačkoj marci u različitim fazama kretanja (ubrzanje,

gases of separate vehicle trade marks in different phases of motion (acceleration phase, phase of mover uniformly, braking phase, idling phase) [3]. The results of numerical tests are generalized and registered in a special database.

Full-scale surveys of city road network in compliance with selection of research objects are subdivided into continuous and selective methods of survey.

The problem of the continuous method of survey is obtaining the information on the basis of observations over all blocks of data. At considerable number of the objects the necessary data can be obtained by a selective method. A problem of the selective observations is obtaining the information on the basis of survey of a part of the data.

The full-scale surveys are conducted in such days of week and season, when the typical conditions of surveyed objects functioning for the survey period of time are ensured; the survey of the objects having temporary or emergency operating models are not applied.

As a result of continuous and selective full-scale surveys of the city road network the following parameters can be solved:

- vehicle traffic intensity for forward and reverse directions;
- traffic structure in compliance with the auto types for forward and reverse directions;
- width of the road;
- maximum speed of motion of different vehicles;
- formation of traffic motion irregularity and their hour, day, week, and season allocation on the city terrain;
- definition of rush-hours and others.

The main problem of the continuous method of road network survey is determining the distribution regularities of season, week and day vehicular traffic intensity with the detection of hour maximums (minimums) for roads of different categories.

Continuous stage of full-scale survey of road network of the Tula central part was conducted in 2 stages: the first stage is the preparatory phase; the second stage is phase of operative realization of surveys.

During the preparatory phase the purposes and problems of the survey were specified; there was a

ravnomerno kretanje, kočenje, mirovanje) [3]. Numerički rezultati se generalizuju i registruju u posebnu bazu podataka.

Kompletna istraživanja gradske mreže puteva dele se prema svrsi na stalna, odnosno kontinualna i namenska, odnosno selektivna istraživanja.

Osnovni problem kod stalnih, odnosno kontinualanih istraživanja, je kompletiranje čitavog bloka podataka. Kod određenog broja objekata neophodni podaci mogu se dobiti selektivnom metodom. Problem kod namenskih, odnosno selektivnih istraživanja je obezbeđivanje iscrpnih podataka na osnovu delimičnih istraživanja.

Kompletna istraživanja se sprovode dnevno, nedeljno ili sezonski, osnosno u periodu kada postoje uslovi koji su tipični za posmatrani segment. Istraživanja se ne sprovode za sisteme koji imaju privremeni ili izvanredni karakter.

Na osnovu kontinualanih i selektivnih istraživanja gradske mreže puteva mogu se odrediti sledeći parametri:

- intenzitet saobraćaja u oba pravca,
- struktura saobraćaja prema tipu vozila u oba pravca,
- širina puta,
- maksimalna brzina kretanja određenih vozila,
- nepravilnosti u odvijanju saobraćaja, lociranje nepravilnosti kao i dnevna, nedeljna i sezonska učestalost u odnosu na lokaciju,
- određivanje saobraćajnih špiceva i sl.

Jedan od problema kontinualnog istraživanja putne mreže je utvrđivanje zakonitosti sezonskog, nedeljnog i dnevnog rasporeda i gustine saobraćaja, kao i određivanje perioda maksimalnog i minimlanog opterećenja za puteve različitih kategorija.

Kontinualno istraživanje putne mreže centralnog dela Tule sprovedeno je u dve faze. Prva faza sastojala se od pripreme, a druga faza prerdstavlja sprovođenje istraživanja.

U toku pripremne faze definisani su ciljevi i problemi. Pripremljene su polazne informacije, kao

preparation of the initial information as the plans of the city and the database-journal for registering observations; the familiarization with the city have been conducted; the results of the surveys conducted for other cities have been analyzed; the content of the work, methods and terms of their being conducted have being worked out; the necessary number of participants have been determined. During the preparatory stage the most critical section of the city road network have been revealed. All the main roads, the local roads and the by-ways have undergone the transport survey, except the access roads, service roads and roads having malfunction.

As the result of full-scale survey of the road network of the central part of Tula city by a continuous method the following data are obtained:

- the most bussed hours, days and months; gaseous emissions pollutant emissions,
- the diagrams of distribution of the traffic motion intensity during the day,
- rush hours for different transport groups
- the possibility of the average daily intensity of the vehicle motion being stated.

The purpose of the development testing is obtaining of the information about fuel rates and lineal pollutant emissions with used gases in the different phases of motion (acceleration phase, braking phase, idling phase, phase of motion with constant value of velocity). The results of computational testing also generalised and recorded in the special database.

The space source with complex geometry and calculated exhausts is formed after importation of all data.

The modelling of gas-dynamics processes in the air surface of the urban terrains is realised with the application of the GAS DYNAMICS TOOL (GDT) software. The given software is intended for modelling in the system of gases and bodies of the arbitrary geometrical form: gas-dynamics calculation for flat, rotationally symmetric and 3D mention flows being conducted; investigation of processes in gases called forth by diffusion, viscosity, thermoreturn, etc. The program is capable to solve wide range of problems with non-stationary flows of non-viscous compressible gases on the basis of the integral equations of the Euler with application of a modified method of final volumes. Quantity of elementary cells of the countable domain isn't practically limited. The Novye-Stokes equations solution algorithm included in the program allows interaction of

što su planovi grada i dnevnik baze podataka za evidentiranje rezultata. Zatim je obavljeno detaljno upoznavanje grada i analiza istraživanja sprovedenih u drugim gradovima; obim radova, metode, linije, uslovi, potreban broj izvršilaca i sl. U toku pripremne faze ustanovljena je najkritičnija deonica gradske putne mreže. Analizirani su glavni putni pravci, sporedni putevi, obilaznice, a izostavljeni su prilazni putevi, servisni putevi i putevi koji su u kvaru.

Na osnovu kontinualnog istraživanja putne mreže grada Tule dobijeni su sledeći podaci:

- najprometniji sati, dani i meseci, emisije gasova, emisije polutanata,
- digagrami dnevnog rasporeda i gustine saobraćaja,
- saobraćajni špicevi za pojedine saobraćajne kategorije i
- prognoza prosečne dnevne gustine saobraćaja po kategorijama.

Cilj sprovedenog testiranja je prikupljanje informacija o kategoriji goriva, emisijama linijskih pollutanata kod gasova u određenim fazama kretanja (ubrzanje, kočenje, mirovanje kretanje konstantnom benzinom) Rezultati testiranja se generalizuju i ubacuju u posebnu bazu podataka.

Nakon unosa svih podataka formira se prostor sa složenom geometrijom i obračunatim otpadnim i izduvnim gasovima.

Modeliranje gas-dinamičkih procesa u površinskom sloju atmosferskog omotača gradskih zona vrši se pomoću softvera GDT (GAS DYNAMICS TOOL). Pomenuti softver namenjen je modeliranju sistema gasova i tela proizvoljnog geometrijskog oblika: gas-dinamički obračun ravnih, rotaciono simetričnih oblika, zatim 3D prikazivanje protoka, istraživanje procesa u gasovima izazvanih difuzijom, viskozitet, termički ciklusi itd. Program je u stanju da reši čitav niz problema vezanih za nestacionarni protok neviskoznih i stišljivih gasova na osnovu Eulerovih integralnih jednačina uz primenu modifikovane metode konačnih zapremina. Algoritam Novi-Stouksove jednačine, koji je sastavni deo programa, omogućava interakciju vazdušnih strujanja sa pojedinim telima,

airflows with bodies, viscous effects in gases and many others ones to be taken into account. Besides there is an opportunity to introduce the corresponding type of boundary conditions to the user: free border, a constant value, pressure, concentration on the border, body, etc.

The program executes the following operations:

- It conducts evaluations with the use of any quantity of initial zones with various gas-dynamics parameters,
- It conducts evaluations with the application of any quantity of objects of any geometrical form distributed in the flow zone,
- It ensures a conservation of an initial configuration with an opportunity of its further use,
- It ensures a view of gas-dynamics parameters all values in any cell of the countable domain the whole all computing process,
- It allows the configuration of the simulated problem to be quickly calculated,
- It carries out record and a view of the time parameter change in any point of the calculated area and
- It represents the results obtained in the videografical forms.

viskoznih efekata u gasovima i mnoge druge. Osim toga postoji mogućnost uvođenja odgovarajućih graničnih uslova: slobodni okviri, konstante, pritisci, koncentracije, forme itd.

Program vrši sledeće operacije:

- analize uz primenu neograničenog broja polaznih zona i niza gas-dinamičkih parametara,
- analizu uz primenu neograničenog broja objekata, bilo kog geometrijskog oblika koji se nalazi u zoni strujanja,
- obezbeđuje očuvanje početne konfiguracije uz mogućnost ponovnog korišćenja,
- obezbeđuje pregled gas-dinamičkih parametara u toku rada na računaru iz postojećih domena,
- omogućava brzi proračun konfiguracije za problem koji se simulira,
- daje pregled i evidenciju promene vremenskih parametara u bilo kom segmentu posmatrane oblasti i
- daje prikaz dobijenih rezultata u video i grafičkoj formi.

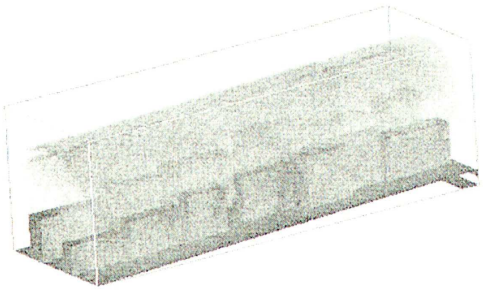

Figure 1 The example of countable domain for the pollutants concentration definition in the built-up areas
slika 1 Primer domena za određivanje koncentracije polutanata u izgrađenim zonama

3 CONCLUSION

The reliability of the results of modelling depends, first of all, on the correct statement of the problem, exact statement of boundary conditions, reliability of the results of statistical data and the data of full-scale surveys. The complex evaluation of the atmospheric air can be made on the basis of the results of gas-dynamics transmission admixtures mathematical modelling in the surround atmospheric layer. That assessment can be applied for determine ecologically unfavourable fields of the industrial city.

3 ZAKLJUČAK

Pouzdanost rezultrata modeliranja zavisi, pre svega, od pravilne postavke problema, precizno definisanih graničnih uslova, pouzdanosti statističkih podataka i podataka sveobuhvatnih istraživanja. Kompleksna analiza atmosferskog vazduha može se izvršiti na osnovu rezultata matematičkog modeliranja gas-dinamičkih transmisija primesa u okolnom atmosferskom omotaču. Ovakva procena je veoma korisna kod određivanja ekološki opasnih zona u industrijskim gradovima.

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