Department of Technologies and Installations for Waste Management

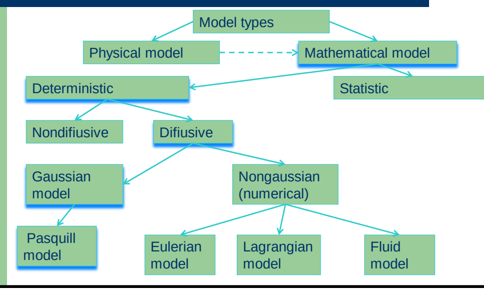
Emission and Transport of Air Pollutants

Lecture 7

Model Pasquilla. Programmes for emission calculation. Low emission.

1

Modelling of the air pollution dispersion



2

Gaussian model – equation of turbulent diffusion – deriviative form of mass principle conservation

$$\frac{\partial C}{\partial t} = -V \cdot \nabla C - \nabla \cdot F_e + Q + R$$

where: C – pollutant concentration, kg/m^3

t – time, s

V – wind velocity vector, m/s

F_e – turbulent mass stream of pollutant, kg/m^{2}s

Q – emission capacity, kg/m^{3}s

R – dry and wet deposition and chemical conversion of pollutant, kg/m^{3}s

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Equation of turbulent diffusion - equation of advective diffusion

$$\frac{\partial C}{\partial t} = -V \cdot \nabla C - \nabla \cdot F_e + Q + R$$

$$\frac{\partial C}{\partial t} = \underbrace{-\left(u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z}\right)}_{\text{advective term}} + \underbrace{\frac{\partial}{\partial x}K_h\frac{\partial C}{\partial x} + \frac{\partial}{\partial x}K_h\frac{\partial C}{\partial y} + \frac{\partial}{\partial x}K_v\frac{\partial C}{\partial z}}_{\text{diffusive term}} + \underbrace{Q + R}_{\text{middle term}}$$

where:

u, v, w – components of wind velocity,

$K_h = K_{xx} = K_{yy}$ and $K_v = K_{zz}$

K_h, K_v – vertical and horizontal turbulent diffusion coefficient

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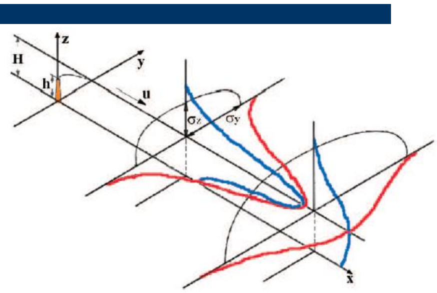
Gaussian model of pollutants dispersion in the atmosphere



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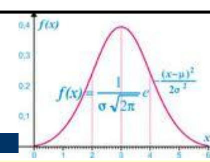
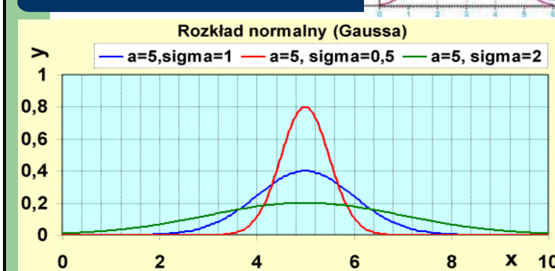
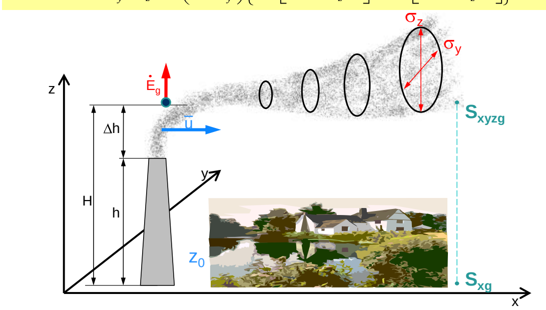
Gaussian distribution





Gaussian plum model of pollutants dispersion in the atmosphere and Pasquill formula for gases

$$S_{xyzg} = \frac{\dot{E}_g}{2\pi \cdot \bar{u} \cdot \sigma_y \cdot \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\} \cdot 1000$$



Pasquill formula of pollutants dispersion in the atmosphere

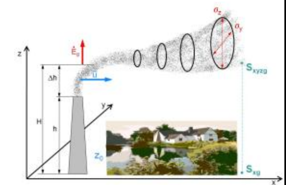
$$S_{xyzg} = \frac{\dot{E}_g}{2\pi \cdot \bar{u} \cdot \sigma_y \cdot \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\} \cdot 1000$$

where:

S_{xyzg} – gas pollutant concentration at the receptor point, μg/m³

$\dot{E}_g$ – emission of gas substance from source situated in point $x_e=y_e=0$, $z_e = H$, mg/s

σ_y, σ_z – horizontal and vertical diffusion coefficient, m



$\bar{u}$ – average wind velocity in layer: from h to H, m/s

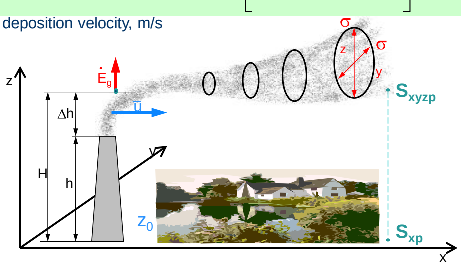
x, *y*, *z* – coordinate of receptor point , for which concentration of substances in air is calculated ,m

H – effective high of emission source , m

Gaussian plum model of pollutants dispersion in the atmosphere and Pasquill formula for fly ash

$$S_{xyzp} = \frac{\dot{E}_p}{2\pi \cdot \bar{u} \cdot \sigma_y \cdot \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left[-\frac{\left(z - H - w_f \frac{x}{\bar{u}}\right)^2}{2\sigma_z^2}\right] \cdot 1000$$

w_f - ash deposition velocity, m/s



Pasquill formula for pollution dispertion on surface of terrain in wind axes and distance x from emission source

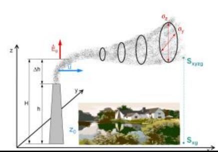
$$S_{xg} = \frac{\dot{E}_g}{\pi \cdot \bar{u} \cdot \sigma_y \cdot \sigma_z} \exp\left(-\frac{H^2}{2\sigma_z^2}\right) 1000$$

gdzie:

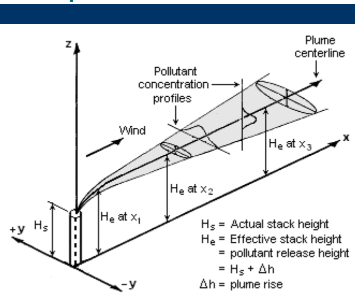
S_{xg} – gas pollutant concentration , μg/m³ , *for y = z= 0*

$$S_{xp} = \frac{\dot{E}_p}{2 \cdot \pi \cdot \bar{u} \cdot \sigma_y \cdot \sigma_z} \exp\left(-\frac{H^2}{2\sigma_z^2}\right) 1000$$

S_{xp} – fly ash concentration, μg/m³ , *for y = z= 0 and* ash deposition velocity w_f=0



Gaussian plum model of pollutants dispersion in the atmosphere



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Diffusion coefficient (Dz.U. nr 16 poz. 67)

Horizontal diffusion coefficient, m

$$\sigma_y = A \cdot x^a$$

Vertical diffusion coefficient, m

$$\sigma_z = B \cdot x^b$$

σ_y, σ_z - standard deviations of the pollutant concentration distribution

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Coefficient A and B (Dz.U. nr 16 poz. 67)

$$A = 0{,}088\left(6m^{-0{,}3} + 1 - \ln\frac{H}{z_0}\right)$$

$$B = 0{,}38m^{1{,}3}\left(8{,}7 - \ln\frac{H}{z_0}\right)$$

$$\frac{H}{z_0} = 10, when \frac{H}{z_0} < 10$$

$$\frac{H}{z_0} = 1500, when \frac{H}{z_0} > 1500$$

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Coefficients (Dz.U. nr 16 poz. 67)

Tablica 2.2 Stałe zależne od stanów równowagi atmosfery

Stała	Stan równowagi atmosfery					
	1	2	3	4	5	6
m	0,080	0,143	0,196	0,270	0,363	0,440
a	0,888	0,865	0,845	0,818	0,784	0,756
b	1,284	1,108	0,978	0,822	0,660	0,551
g	1,692	1,781	1,864	1,995	2,188	2,372
C_1	0,213	0,218	0,224	0,234	0,251	0,271
C_2	0,815	0,771	0,727	0,657	0,553	0,457

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Maximal concentration of pollutants in the air

Maximal concentration of gas substance in the air, and suspended ash for single source, averaged for **one hour** in **particular meteorological situation:**

$$S_{mg} = C_1 \frac{\dot{E}_g}{\bar{u} \cdot A \cdot B}\left(\frac{B}{H}\right)^g 1000$$

$$S_{mp} = C_1 \frac{\dot{E}_p}{2 \cdot \bar{u} \cdot A \cdot B}\left(\frac{B}{H}\right)^g 1000$$

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Maximal concentration of pollutants in the air

$$S_{mg} = C_1 \frac{\dot{E}_g}{\bar{u} \cdot A \cdot B}\left(\frac{B}{H}\right)^g 1000 \qquad S_{mp} = C_1 \frac{\dot{E}_p}{2 \cdot \bar{u} \cdot A \cdot B}\left(\frac{B}{H}\right)^g 1000$$

S_{mg} - Maximal concentration of gas substance in the air, , μg/m^3

S_{mp} - Maximal concentration of suspended ash in the air, , μg/m^3

C_1, g - Constant coefficient depended on equilibrium state of atmosphere

$\dot{E}_g$ - Maximal emission of gas substances, mg/s

$\dot{E}_p$ - Maximal emission of suspended ash, mg/s

$\bar{u}$ - Average wind velocity in layer from h to H, m/s

A, B - Coefficient depended on m, z_0, H

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Maximal concentration of pollutants in the air

Distance from the source, where concentration of pollutant, as well as ash, reaches **maximal value** for single source, averaged for **one hour** in **particular meteorological situation**.

$$x_m = C_2\left(\frac{H}{B}\right)^{\frac{1}{b}}$$

C_2, b – constant coefficient depended on equilibrium state of the atmosphere

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Maximal concentration of pollutants in the air

- **S_m and S_{mp}** value should be **calculated for 36 meteorological situations**
- From group of 36 values of **S_m** for each substance, the maximum value is chosen and denoted **S_{mm}**.
- Terrain of installation is excluded from area, where calculations are carried out.

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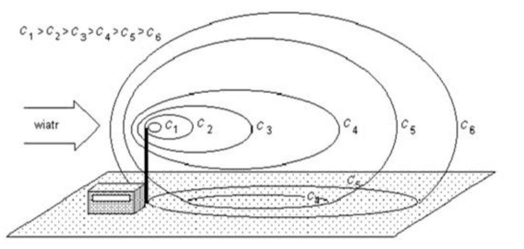
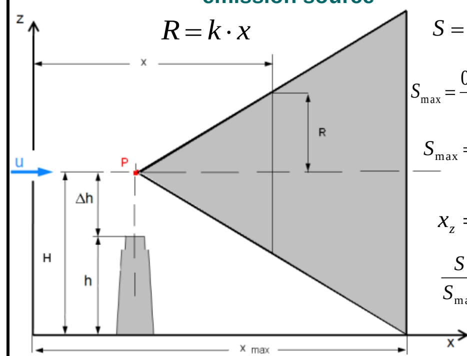
Maximal concentration of pollutants in the air



Simplified model of pollutants dispersion from point emission source

$$R = k \cdot x$$



$$S = \frac{0{,}318 \cdot \dot{E}}{u \cdot R^2}$$

$$S_{max} = \frac{0{,}318 \cdot \dot{E}}{u \cdot H^2} \quad \text{or} \quad S_{max} = \frac{0{,}234 \cdot \dot{E}}{u \cdot H^2}$$

$$x_z = 4{,}47 \frac{H}{k}$$

$$\frac{S}{S_{max}} = 0{,}05$$

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$$x_z = 4{,}47 \frac{H}{k}$$

$$\frac{S}{S_{max}} = 0{,}05$$

R – radius of pollutant trail
u – wind velocity on height H,
k- atmosphere diffusion coefficient, (cross related to x direction)
E- pollutant emission, kg

H – effective source height,
x_z – range, where source P has effect on, where concentration drops to 5% of its maximal value

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Data required to calculation

- Emission source parameters: height [m], outlet diameter [m], gas velocity at the outlet [m/s], gas temperature [K],
- Pollutants emission [kg/h],
- Background of substances [µg/m³]
- Ambient temperature [°C],
- Work period during the year [h],
- Shape of the area and roughness factor,
- Compass rose.

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Pollutants backgrounds for installation in Kęty

	Substance	Reference value in µg/m³ averaged for period		Background[µg/m³]	Notes
		1 hour	1 year		
1	Aceton	350	30	3	10% D_a
2	Akrylaldehyd (akroleina)	10	0,9	0,09	10% D_a
3	Cykloheksan	10	1	0,1	10% D_a
4	Cykloheksanon	40	3,5	0,35	10% D_a
5	**Nitrogen dioxide**	**200**	**40**	**26**	-
6	Sulphur dioxide	350	30	3	10% D_a
7	Etylobenzen	500	38	3,8	10% D_a
8	Alkohol dwuacetonowy	150	7,9	0,79	10% D_a
9	Izocyjaniany	10	1,3	0,13	10% D_a
10	Ksylen	100	10	1	10% D_a
11	Alkohol izobutylowy	300	26	2,6	10% D_a
12	Octan butylu	100	8,7	0,87	10% D_a
13	Octan etylu	100	8,7	0,87	10% D_a
14	**Suspended ash PM 10**	**280**	**40**	**30**	-
15	**Carbon monooxide**	**30000**		-	-
16	Aliphatic hydrocarbones	3000	1000	100	10% D_a
17	Aromatic hydrocarbones	1000	43	4,3	10% D_a

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Pollutants backgrounds for installation in Kęty

Contamination state of air described on the basis of information from Voivodeship Inspectorate of Environment Protection in Cracow , 22. 02. 2007

Tabela 2. Present air contamination state in Kęty

Substance	Annual average concentration [µg/m³]	Permissible value [µg/m³]	% of permissible value
Suspended ash PM 10	**30**	40	75
Nitrogen dioxide	**26**	40	65
Lead	0,04	0,5	8
Benzene	3,2	5	64

Quality of air in area around the installation is influenced by affecting industrial plants, roads, dust and pollutants emission from local sources (chimneys, boilers, etc.).

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Programmes used to modelling of the air pollution dispersion

- **Sozat – EK100 W / ATMOTERM**
- **Komin / Rww/ EcoSoft**
- **Emitor / Obserwator imisji / Polstage**
- ISC 3
- ZANAT
- URFOR

- **COPERT**
- HBEFA (Niemiecki)
- INRETS (Francuski)

} For line source of emission

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Programmes used to modelling of the air pollution dispersion

- CALMET/CALPUFF (California) – Lagrangian model
- MISCAM
- STEM II
- RADM
- GATOR
- POLSOXNOX
- HARWELL LABORATORY
- AVACTA
- ATSTEP
- SPM
- EMEP
- RPM
- RIMPUFF
- ADPIC
- ARCO
- MDMS
- CAR

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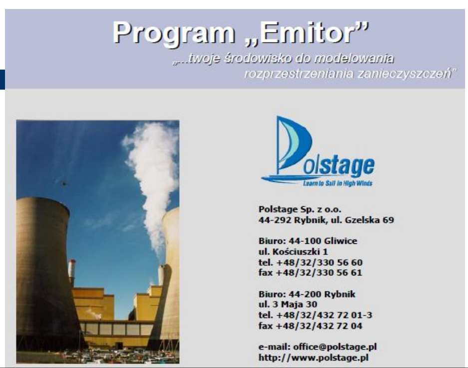
„Emitor” Programme



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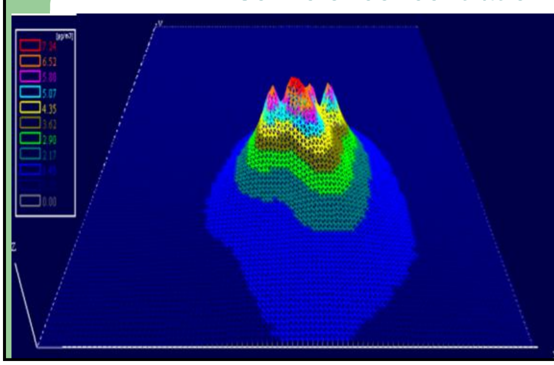
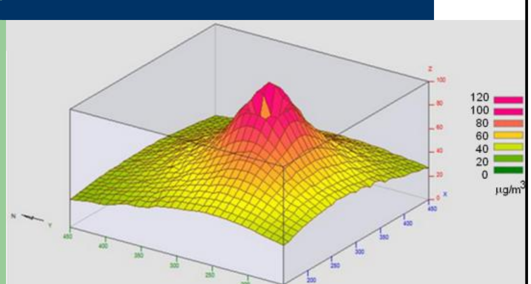
„Obserwator imisji” – isoline of concentration



„Komin” Programme
Isoline of maximal concentration of sulfer dioxide, $\mu g/m^3$



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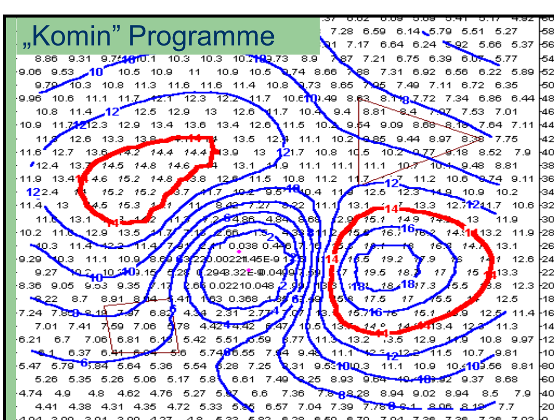
„Komin” Programme



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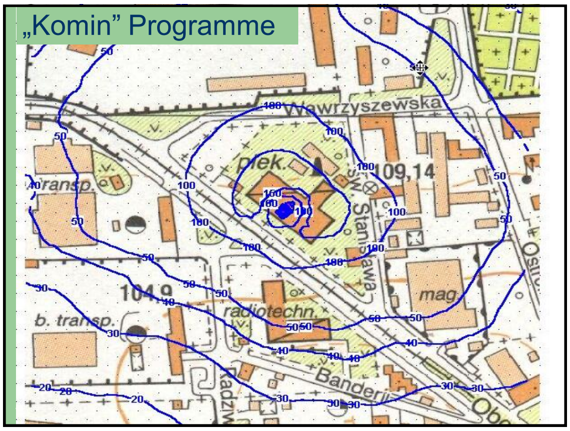
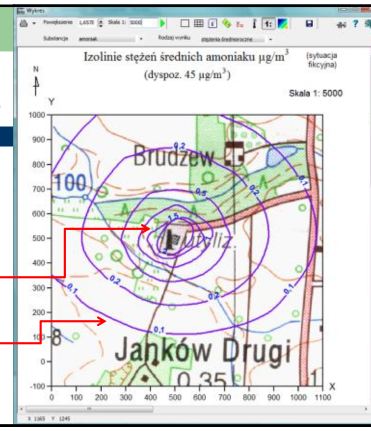


„Komin" Programme

Isoline of ammonia concentration

1,5 μg/m³

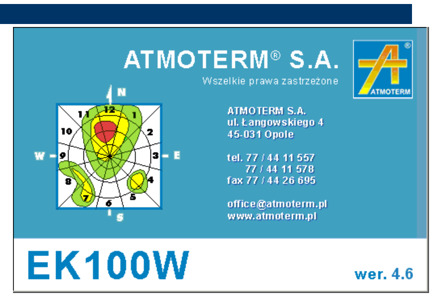
0,1 μg/m³



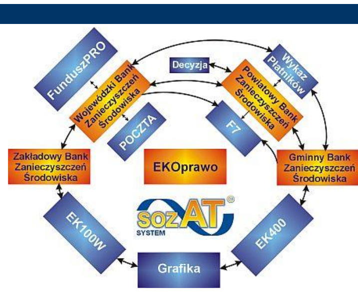
COPERT software

COPERT is model and programme to determination of air pollution from transport means

EK-100W software contained in SOZAT package



EK-100W software contained in SOZAT package

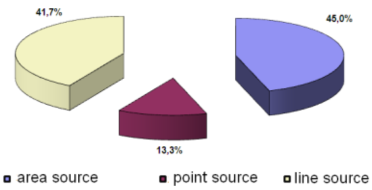


TABL.5(140). CAŁKOWITA EMISJA[a] DWUTLENKU SIARKI, TLENKÓW AZOTU I PYŁÓW
TOTAL EMISSION[a] OF SULPHUR DIOXIDE, NITROGEN OXIDES AND PARTICULATES

WYSZCZEGÓLNIENIE	2000	2005	2007	2008	SPECIFICATION
	w gigagramach / *in gigagrams*				
DWUTLENEK SIARKI / ***SULPHUR DIOXIDE***					
O G Ó Ł E M	**1511**	**1222**	**1216**	**999**	***TOTAL***
Energetyka zawodowa	805	673	664	448	*Power generating plants*
Energetyka przemysłowa	265	202	200	192	*Industrial power plants*
Technologie przemysłowe	91	56	25	24	*Industrial technologies*
Inne źródła stacjonarne[b]	309	290	324	333	*Other stationary sources[b]*
Źródła mobilne	41	1[c]	2[c]	2[c]	*Mobile sources*
TLENKI AZOTU[d] / ***NITROGEN OXIDES[d]***					
O G Ó Ł E M	**838**	**811**	**860**	**831**	***TOTAL***
Energetyka zawodowa	237	246	247	226	*Power generating plants*
Energetyka przemysłowa	93	125	96	84	*Industrial power plants*
Technologie przemysłowe	75	54	51	48	*Industrial technologies*
Inne źródła stacjonarne[b]	120	74	118	122	*Other stationary sources[b]*
Źródła mobilne	313	312	349	350	*Mobile sources*
PYŁY / ***PARTICULATES***					
O G Ó Ł E M	**464**	**430**	**430**	**421**	***TOTAL***
Energetyka zawodowa	64	39	36	24	*Power generating plants*
Energetyka przemysłowa	19	13	12	9	*Industrial power plants*
Technologie przemysłowe	72	53	62	58	*Industrial technologies*
Inne źródła stacjonarne[b]	248	257	243	249	*Other stationary sources[b]*
Źródła mobilne	61	68	77	82	*Mobile sources*

Contribution of sources in PM 10 emission (Białystok)

d



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PAH emission depending on organization of combustion process

Fuel	Application	BaP emission index, mg/GJ
Hard coal	Pulverised coal boilers	0,47
	Boilers with mechanical stoker	1,9-152
	Local small boilers	188
	Household furnace	910
Oil	Household furnace	0,28-560
Natural gas	Household furnace	0,019
Petrol	Motor vehicle	0,57
Disel oil	Motor vehicle	2,18

Exam questions

1. What is Pasquill model used for?
2. What parameters influence diffusion coefficient of the atmosphere σ_y, σ_z?
3. Draw pollutant dispersion model.
4. Enumerate three programmes for air pollution dispersion modelling.
5. What is isoline of concentration? Explain by drawing.
6. For which substances, when and why pollutant background in urban agglomeration in Poland is higher than $0,1D_a$?

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