Department of Technologies and Installations for Waste Management

Emission and Transport of Air Pollutants

Lecture 5

Transport of air pollutants

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Source of emission

- **Point emission source (eg. stack),**
- **Line emission source (eg. cars on a road)**
- **Area emission source (eg. landfill),**

Set of Point emission sources
(collection of a few point emission source or replacement of line or area emission sources)

2

Point emission source

Low emission

Set of 2 point emission sources

3

Point emission source

Roofed chimney

4

Line emission source

5

Area emission source

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Factors which has influence on spatial dispersion of pollutants in atmospheric air

1. Emission level,
2. Technical parameters of stack **(plum rise),**
3. Physical and chemical processes in the atmosphere,
4. Absorption of pollutants by clouds, soils and plants,
5. Leaching of pollutants by precipitations (rain, snow, etc.)
6. Transport of pollutants:
   - Meteorological conditions: **compass rose**, air temperature, states of **atmosphere equilibrium (6)** and corresponding meteorological situations (36).
   - Terrain topography conditions (**terrain roughness**).

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Effective stack height H

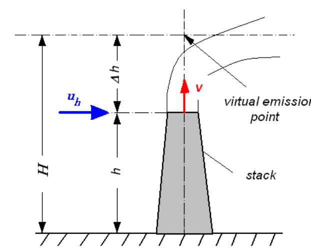
H=h+Δh

u_h – wind velocity on outlet stack height, m/s

v – outlet gas velocity, m/s

Δh – plume rise, m

h – actual stack height, m



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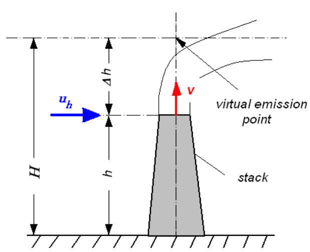
Effective stack height H

When H=h ?

Δh =0

1) for roofed stack
2) horizontal outlet emission source,



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Plume rise Δh

- Plume rise is an effect of two mechanism: kinetic energy and uplift pressure of outlet gas.
- Plume rise depends on outlet gas velocity (v), heat emission - enthalpy ($\dot{Q}$) and wind velocity (u_h) on stack height.

$$\dot{Q} = \dot{V} \cdot c_p \cdot T$$

$$\dot{Q} = \frac{\pi \cdot d^2}{4} \cdot v \cdot 1{,}3 \cdot \frac{273{,}15}{T} \cdot (T - T_{air})$$

where

C_p= 1,3 kJ/m$^3{}_u$K, gas specific heat capacity for constant pressure ,

T – outlet gas temperature, K

d- stack diameter, m

d_r – stack diameter replacement for rectangular outlet of $d_r = \sqrt{\frac{4pq}{\pi}}$

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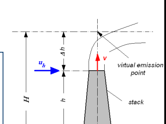
Holland formula when $0 \le \dot{Q} \le 16\,000$ kJ/s

a)
$$v \le 0{,}5 \cdot u_h \qquad \Delta h = \Delta h_H = 0$$

b)
$$v \ge u_h \qquad \Delta h = \Delta h_H = \frac{1{,}5 \cdot v \cdot d + 0{,}00974 \cdot \dot{Q}}{u_h}$$

c)
$$0{,}5 u_h < v < u_h \qquad \Delta h = \Delta h_H = \frac{1{,}5 \cdot v \cdot d + 0{,}00974 \cdot \dot{Q}}{u_h} \cdot \frac{v - 0{,}5 \cdot u_h}{0{,}5 \cdot u_h}$$



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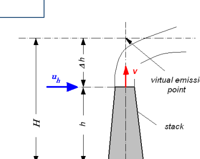
Concawe formula

when $\dot{Q} \ge 24\,000$ kJ/s

$$\Delta h = \Delta h_C = \frac{1{,}126 \cdot \dot{Q}^{0{,}58}}{u_h^{\;0{,}7}}$$



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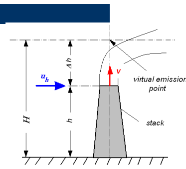
Holland & Concawe formula

when $16 < \dot{Q} < 24\,000$ kJ/s



$$\Delta h = \Delta h_H \cdot \frac{(24\,000 - \dot{Q})}{8\,000} + \Delta h_C \cdot \frac{(\dot{Q} - 16\,000)}{8\,000}$$

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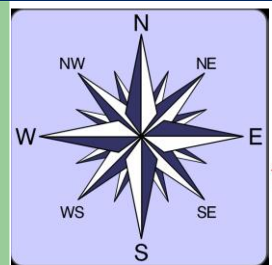
Compass rose



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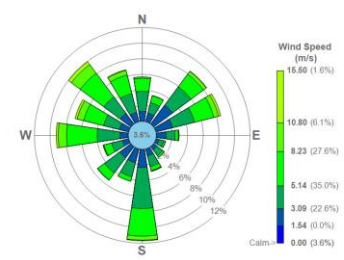
Compass rose



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Compass rose – annual Szczecin - Dąbie

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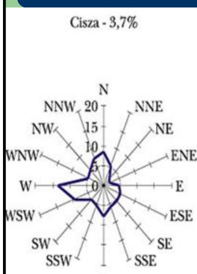
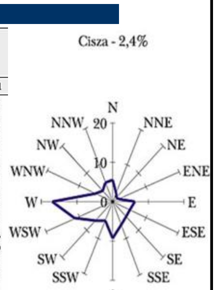
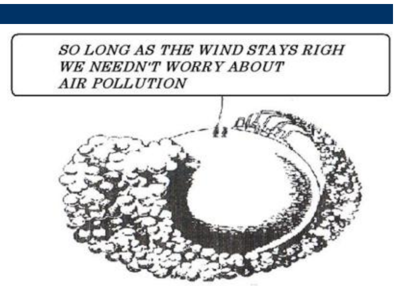
Compass rose – annual - Gorzów, 2000 and 2001



Kierunek wiatru	Częstotliwość wiatrów z poszczególnych kierunków [%]	
	2000	2001
N	8,4	5,6
NNE	5,1	2,5
NE	2,6	1,4
ENE	1,6	1,7
E	4,6	6,1
ESE	5,4	5,2
SE	5,2	5,1
SSE	5,6	6,2
S	7,8	9,2
SSW	5,2	5,2
SW	5,0	6,8
WSW	9,1	11,5
W	13,3	16,9
WNW	5,0	5,3
NW	5,1	3,8
NNW	7,3	5,1
C	3,7	2,4



Influence of wind direction on air pollution



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Meteorological parameters (Dz.U. nr 16poz 87)

- wind velocity (u_h) on stack height

$$u_h = u_a \cdot \left(\frac{h}{14}\right)^m \qquad \text{dla } h \leq 300 \text{ m}$$

$$u_h = u_a \cdot \left(\frac{300}{14}\right)^m \qquad \text{dla } h > 300 \text{ m}$$

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Meteorological parameters (Dz.U. nr 16poz 87)

- Average wind velocity in following layer: from ground level to effective stack height H

$$u_s = \frac{u_a}{1+m} \cdot \left(\frac{H}{14}\right)^m \qquad dla \;\; H \leq 300m$$

$$u_s = \frac{u_a}{1+m} \cdot \left(\frac{300}{14}\right)^m \cdot \left[(1+m) - m \cdot \frac{300}{H}\right] \qquad dla \;\; H > 300m$$

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Meteorological parameters (Dz.U. nr 16poz 87)

- Average wind velocity in following layer: from actual stack height h to effective stack height H

$$\bar{u} = u_h = u_a \cdot \left(\frac{h}{14}\right)^m \qquad dla \quad h = H$$

$$\bar{u} = \frac{u_a}{(H-h) \cdot (1+m) \cdot 14^m} \cdot [H^{1+m} - h^{1+m}] \;\; dla \;\; H \leq 300m \; i \; H \neq h$$

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Meteorological parameters (Dz.U. nr 16poz 87)

- Average wind velocity in following layer: from acctual stack height h to effective stack height H

$$\bar{u} = \frac{u_a}{(H-h) \cdot 14^m} \cdot \left[\frac{(300^{1+m} - h^{1+m})}{(1+m)} + (H-300) \cdot 300^m\right]$$

$$dla \quad h < 300 \; m \;\; i \;\; H > 300 \; m$$

$$\bar{u} = u_a \cdot \left(\frac{300}{14}\right)^m \qquad dla \; h \geq 300m$$

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Meteorological parameters (Dz.U. nr 16poz 87)

- When values of wind velocity u_h and $\bar{u}$ are smaller than 0,5 m/s, to substance concentration calculation in air assume 0,5 m/s

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Meteorological parameters (Dz.U. nr 16poz 87)

coefficient of horizontal diffusion in air

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

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

coefficient of vertical diffusion in air

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

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

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Meteorological parameters (Dz.U. nr 16poz 87)

If H/z_0 is not 10 to 1500 to calculate A and B coefficients assume:

$$H/z_o = 10, \text{ gdy } H/z_o < 10$$
$$H/z_o = 1500, \text{ gdy } H/z_o > 1500$$

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6 categories of atmosphere stabilyty

Atmosphere stabilyty categories	Wind velocity on reference height of 14 m, u_a [m/s]
1 - extremly unstable	1-3
2 - unstable	1-5
3 - lightly unstable	1-8
4 - neutral	1-11
5 - moderately stable	1-5
6 - stable	1-4

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Meteorological connstant for 6 categories of atmosphere stabilyty

Constant	Stabilyty categories					
	1	2	3	4	5	6
m	0,08	0,143	0,196	0,27	0,363	0,44
a	0,888	0,865	0,845	0,818	0,784	0,756
b	1,284	1,108	0,978	0,822	0,66	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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Terrain roughness factor z_0, Dz.U. nr 16, poz 87, 2010, App. 3, table 4

	Type of terrain	Factor z_0
1	water (lakes, etc.)	0,00008
2	meadows, grass-lands	0,02
3	fields	0,035
4	orchards, thickets, copses	0,4
5	forests	2,0
6	Dense rural buildings	0,5
7	Towns up to 10000 inhabitants	1,0
8	City between 10 000 to 100 000 inhabitants	
8.1	- low buildings	0,5
8.2	- high buildings	2,0

	Type of terrain	Factor z_0
9	City between 100 000 to 500 000 inhabitants	
9.1	- low buildings	0,5
9.2	- medium buildings	2,0
9.3	- high buildings	3,0
10	City above 500 000 inhabitants	
10.1	- low buildings	0,5
10.2	- medium buildings	2,0
10.3	- high buildings	5,0

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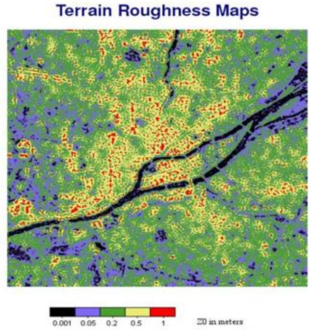
Roughness of terrain

Terrain Roughness Maps



Terrain roughness separated into five classes over the city Nantes in France based on radar images. Data Credit: ESA.

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Questions for exam

1. Enumerate types of emitters - a sources of emission.
2. What influences spatial dispersion of pollutants in the air?
3. Explain by drawing, what is an effective stack height and plume rise?
4. Under what condition an effective stack height equals geometric stack height?
5. What formulas are applied in calculation of plume rise?
6. What represents compass rose?
7. Enumerate terrains (at least 7), where according to polish law (Dz.U. nr 16, poz. 87, 2010) terrain roughness factor equals z_0.
8. Calculate effective stack height H in case when heat stream of emitted gas to atmosphere is 12 MW, geometric stack height is 50 m, outlet diameter is 1,5 m, exhaust gas velocity is 18 m/s and wind velocity is 3,5 m/s at stack outlet height.

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