ENVIRONMENTAL EFFECTS OF SUSPENDED AND TOXIC MATERIALS FROM COAL AND PEAT COMBUSTION

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Contents

Summary

The atmosphere plays a major role in the global processes supporting life on Earth. Gaseous pollutants emitted in the course of human activities become constituents of the air. According to published reports, almost one-third of human-produced pollutants were an effect of heat and electricity production from combustion of fossil fuels. Pollution of the atmospheric air in many different ways affects both living organisms and inanimate objects.

During the combustion process, fly ash particles of 0.01 to 100 μm diameter are emitted. These particles contain elements identified as being hazardous, such as As (arsenic), Cd (cadmium), Cr (chromium), Hg (mercury), Pb (lead), and Sb (antimony). Especially dangerous for human health, remaining in the lungs, are those equal to, or less than 10 μm in diameter referred to as $PM_{10,}$ and the fine particles of diameter ≤ 2.5 μm called $PM_{2.5}$. PM_{10} and $PM_{2.5}$ have been associated with health effects across several population studies.

During incomplete combustion of coal, trace concentrations of carbon monoxide, a toxic gas showing a large affinity to hemoglobin and obstructing oxygen transport in blood, are emitted. Other gaseous pollutants like sulfur dioxide and nitrogen oxides have a harmful influence on vegetation, cause soil and water acidification, and have a negative influence on human health.

Some halogens, such as chlorine, fluorine, bromine, and iodine are in ppm concentrations in coal. During combustion, they are emitted as anhydron acids, which exert a similar effect to SO_2 and NO_x on the natural environment.

1. The Atmosphere and its Role

The atmosphere plays a major role in the global processes supporting life on Earth. Photosynthesis, a process, which uses up carbon dioxide and produces oxygen, takes place in the atmosphere. The atmosphere also plays an important physical role as a heat reservoir. Heat absorbed by the atmosphere during daylight hours is released overnight, helping to maintain a balanced temperature. Without the atmosphere, Earth’s surface temperature would rise greatly when bathed in sunlight, but fall enormously in the dark.

The oxygen contained in the atmosphere is necessary for maintaining the life of organisms that use it for their metabolism processes. Gases show infinite mutual solubility and that is why all gaseous pollutants emitted in the course of human communal and industrial activities become constituents of the air. These pollutants can enter the lungs of living creatures where they can either be directly absorbed or captured on small particles of dust (Figure 1). The combustion of fossil fuels plays a significant role in emission of gaseous and solid pollutants.

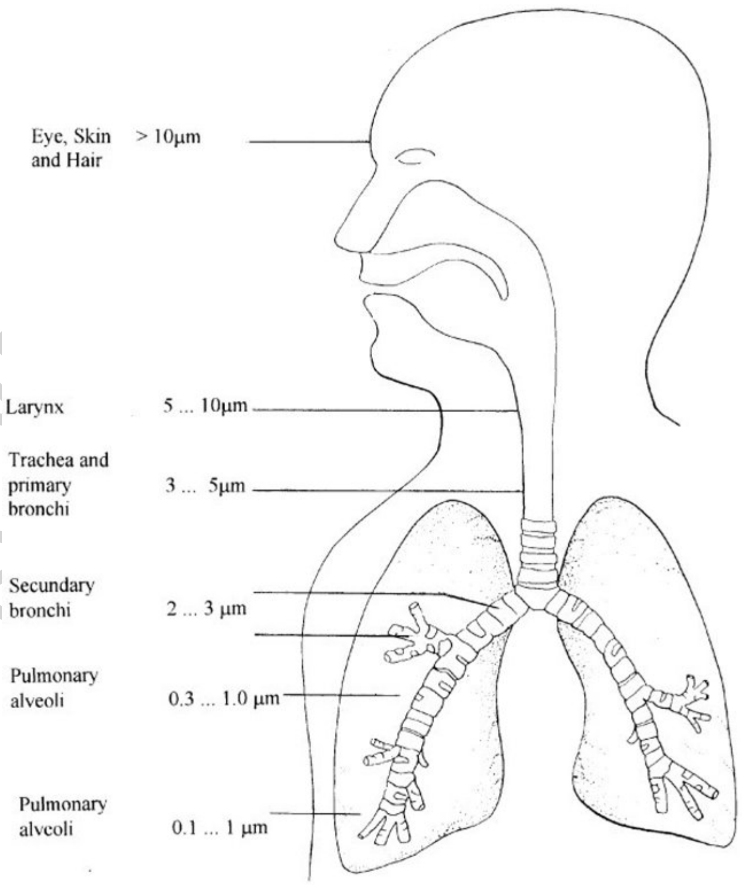

Figure 1. Particle deposition in the different areas of the respiratory tract in dependence of the mean of the particles.

According to the relevant data collected in the 1970s, 27% of human-produced pollutants were from the operation of heat and electricity production stations. Considering the fact that many industrial processes are based on energy production by means of combustion of fossil fuels (e.g. metallurgy), it becomes clear that this particular manner of energy generation constitutes the greatest hazard to the natural environment. Global amounts of pollutants emitted by electropower stations of capacity exceeding 1000 MW are shown in Table 1. The main components of gases produced during combustion of coal are nitrogen, carbon dioxide, water vapor, and oxygen remaining after combustion. Depending on the composition of coal, conditions of the combustion process, and the flue gas purification installations used, other gases and pollutants formed in the process can be SO_2, SO_3, NO, NO_2, CO, HCl, NH_3, fly ash, and a wide range of compounds and elements occurring in trace amounts.

Pollutants	**Organic fuel - fired power plants**		
	coal*) $2.3 \cdot 10^6$ Mg/year	**fuel oil**) $1.57 \cdot 10^6$ Mg/year**	**gas $1.9 \cdot 10^9$ m^3/year**
Non-radioactive (mg/y)			
sulfur oxides	$138 \cdot 10^3$	$98 \cdot 10^3$	1.6
nitrogen oxides as NO_2	$20.9 \cdot 10^3$	$21.8 \cdot 10^3$	$12.2 \cdot 10^3$
carbon monoxide	21	9	traces
Higher aromatic hydrocarbons	210	680	-
aldehyde	50	120	30
Fly ash	$4.5 \cdot 10^3$	730	450
Radioactive (Ci/y)			
Ra^{226}	$17.2 \cdot 10^{-3}$	$0.15 \cdot 10^{-3}$	-
Ra^{228}	$18.8 \cdot 10^{-3}$	$0.15 \cdot 10^{-3}$	-

* sulfur content 3.5% (15% sulfur remains in the ash);
ash content 9%; flue gas purification degree 97.5%.
** sulfur content 1.6%; ash content 0.05%.

Table 1. Annual emission of pollutants from 1000 MW electropower stations using combustion of fossil.

These pollutants are emitted to the atmosphere where, due to various transport processes, they are frequently carried over long distances, undergo many chemical and physical transitions, and then precipitate and deposit in the soil or surface waters. For some pollutants, their residence time in the atmosphere can be very long (see *Environmental Effects of Fossil Fuel Combustion*).

Most of pollutants are discharged into the boundary layer (Figure 2), which is the thin layer of the atmosphere in contact with Earth's surface where the airflow is frequently turbulent because of surface roughness. Many pollutants, especially the larger particulates (1–10 μm) remain in the boundary layer but gases and smaller aerosol particles (< 5 μm) are transferred into the above troposphere zone by vertical movements in thermal plumes and storms, flowing over mountains. The temperature of air falls with altitude in the troposphere up to the tropopause where the temperature gradient is reversed to around 50 km. Tropopause occurs at around 6–8 km at the poles and 17 km at the equator. Troposphere is the zone of greatest significance to living organisms.

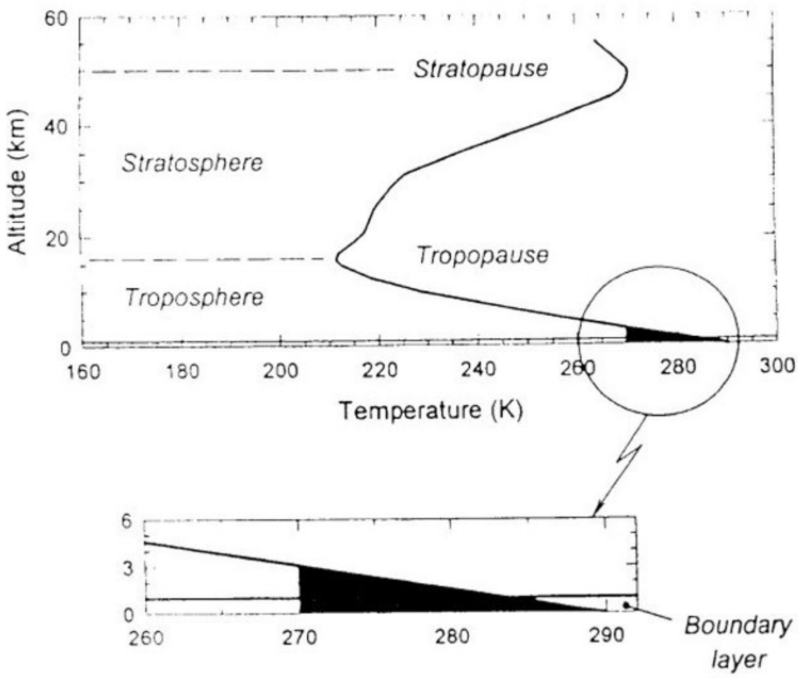

Figure 2. Regions of the atmosphere.

The temperature in the troposphere lowers with altitude to reach approximately -56°C at its upper boundary. Water content in the troposphere is far from being constant because the bulk of water evaporated from lands, seas, and oceans is highly changeable. Also, cloud cover and level of precipitation change depending on atmospheric circulation tendencies. Almost all of the water vapor in the atmosphere is contained in the troposphere. The water contained in the atmosphere in its various forms, such as clouds, droplets of rain, fog, and aerosols; along with a number of pollutants (metal ions, among others) play a major role in the chemistry of the atmosphere.

The role of these heterogeneous reactions mustn’t be neglected in spite of the fact that the volumetric fraction of droplets in a cloud is very small, of an order of 10^{-6}-10^{-7}, while the volumetric fraction of clouds in the troposphere is approximately $5{\cdot}10^{-2}$. This applies, in particular, to the oxidation of sulfur dioxide and the formation of acid rains.

The stratosphere is the next zone above the troposphere (Figure 3) and it consists mainly of N_2, O_2, and water, with some O and ozone. Since the tropopause is characterized by low temperatures, water condensation and the formation of ice crystals occurs there. Very small water content in stratosphere in the form of ice crystals is reflected by the phenomenon of formation of the so-called pearly clouds at altitudes of approximately 20–25 km. The lower layer of the stratosphere is almost perfectly isothermic. Rapid growth of temperature occurs at a higher altitude, starting at about 25 km, at the base of the ozone layer. It is the UV absorption that causes the continual growth of temperature. Ozone concentration in the middle part of this layer equals 10 ppm. Despite the low concentration, ozone is capable of absorbing UV with a wavelength range between 200 nm and 330 nm. Ozone is a highly reactive and unstable substance, but it persists in the stratosphere due to low air pressure, which in this zone varies in the range of 0.1–0.001 atm. This means that the mean free path between collisions is quite long, thus reducing the probability of intermolecular reactions. This also explains why in the more remote areas of Earth's surface spheres (mesosphere, thermosphere) such highly reactive particles as O_2^+, NO^+ and O^+ can survive even though they would not exist close to the surface for any significant time. These species absorb short wavelength solar radiation and play a role similar to ozone in maintaining life on Earth.

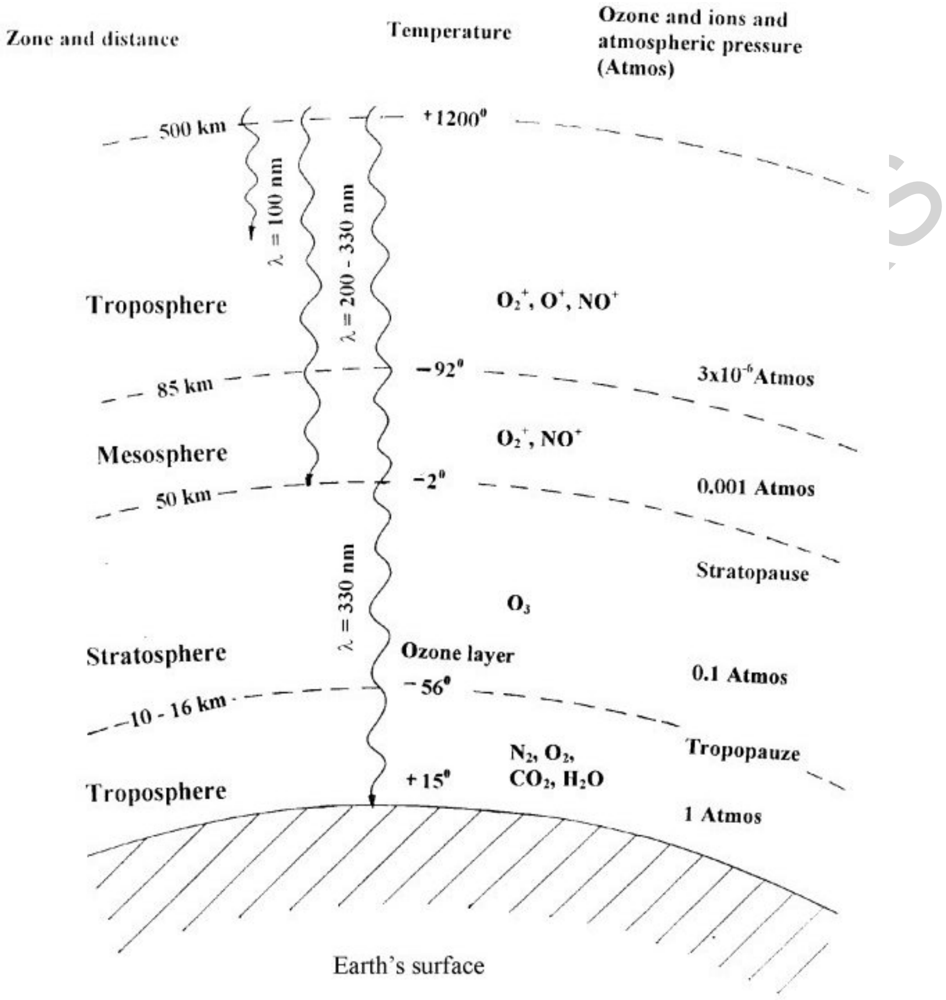

Figure 3. The major zones of the Earth's atmosphere.

Pollutants do not normally enter the mesosphere. The transport of atmospheric pollutants depends on the height they reach in the atmosphere, their particle size in case of dust, and climatic factors. Little transfer of air and pollutants occurs between the northern and southern hemispheres in the troposphere, but some transfer occurs between the troposphere and the stratosphere near the equator and in other places. Explosions and volcanic eruptions inject some pollutants directly into the stratosphere. Gaseous pollutants tend to remain in the stratosphere for a long time because of the lack of washout.

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Biographical Sketch

Andrzej Grzegorz Chmielewski was born in Warsaw in 1943. In 1967 he graduated from the Warsaw University of Technology where he obtained his Ph.D. (1974) and D.Sc. (1984) in chemical engineering. He was appointed Professor in 1992. Six Ph.D. theses and 15 M.Sc. diploma theses were performed under his supervision. In 1967-1983 he was employed at the Warsaw University of Technology (Institute of Process and Chemical Engineering). In 1976-1977 he worked as Postdoctoral Research Associate at the Chemistry Department, University of Tennessee, Knoxville, USA.

Since 1983 he has been working at the Institute of Nuclear Chemistry and Technology, at the beginning as Head of the Department and since 1986 till 2001 as Scientific Director of the Institute. Recently he holds position of the Head of the Department at the Institute and position of the Professor at the Warsaw University of Technology (Department of Chemical and Process Engineering). He has lectured in Japan, Brazil, Syria and Saudi Arabia and served as UN expert to China, the Philippines, Iran, Brazil, Ukraine, Chile, Malaysia and South Korea. He is author and co-author of over 100 papers, two textbooks and over 45 patents (including patents in the USA (3), Germany (2), Canada, Japan, China, Russia, Ukraine). Many of invented solutions were implemented in industry. Among them new type wastewater equilizer-clarifier constructed at the biggest Polish refinery Orlen, Plock and the installation for electron beam flue gas purification from SO_2 and NO_x for 100 MW_e block at EPS Pomorzany, Szczecin (second plant in the world using this process). In 1999 he was awarded with the title “Engineer of the Year” by prestigious Polish professional journal “Technical Review”.

Professor Chmielewski is the Editor-in Chief of the scientific journal “Nukleonika.” Vice-chairman of the Atomic Energy Council, a member of the Board and in the years 1999-2001 President of the Polish Nuclear Society, vice-president of the Council of the Radiation Research Foundation, member of the Advisory Board of the “Europe Nuclear Worldscan” (ENS, Switzerland), a member of the Scientific Council of many Institutes.