STUDIORUM PROGRESSUS

Suspended Particulate Matter and Benzo-(a)pyrene Immissions

Measurements of particulate matter immissions and 3.4 benzpyrene were carried out at 6 measuring points in and around Zürich in 1971/72. The measuring points differred according to their immediate surroundings; they were subdivided into industrial zone, heavy traffic spots, residential area and recreation ground. The LIB-method was used to collect the particulate matter. Each dust test was analyzed with a fluorescence spectroscopic measuring method. This made it possible to determine the extent of 3.4 benzopyrene and 11,12 benzfluoranthene together with a gauge for the total content of polyaromatic hydrocarbon. Differences in locality as well as variations in time were assessed. As meteorological parameters, temperature, inversions, humidity of the air, wind strength and sunlight hours were taken into consideration in the evaluation.

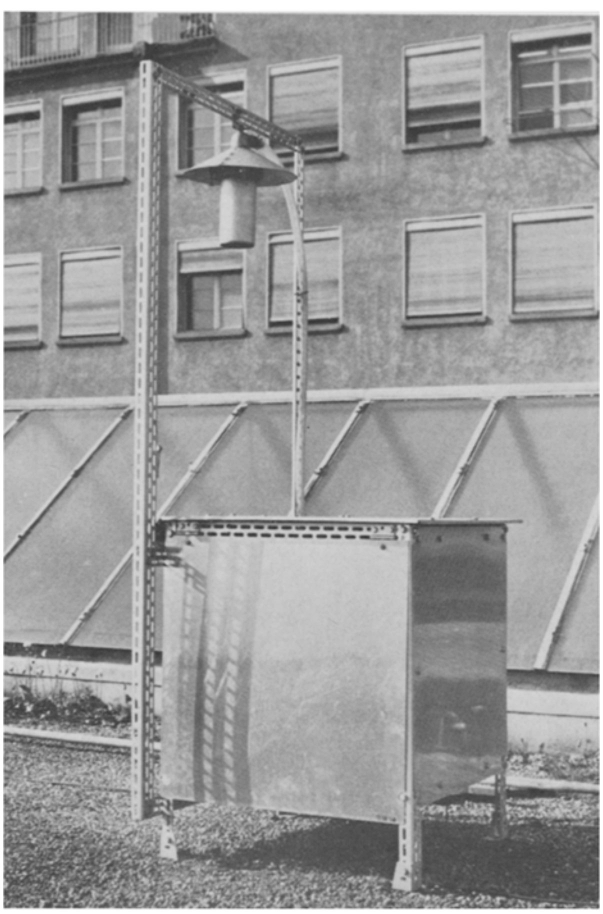

Fig. 1. Measuring apparatus for particulate matter with filter head and aggregate casing (LIB-procedure). By means of a rotary valve pump outside air is sucked vertically through the cylindric adapter tube passing a glass fibre filter. The volume of the absorbed air is measured with a gas-meter. The suction speed is approx. 0.5 m/s so that soot particles with a diameter greater than 15–20 μm will settle before reaching the filter. Thus they are not included in the measuring. After taking samples, the separated (particulates) is gravimetrically determined and the particulate matter immission determined in μg/m³.

Clean air is an important prerequisite for the health of man. However, especially in closely inhabited agglomerations, it is partly not available any more due to increasing industrialization. Formerly, air pollution was mainly perceived as being an annoyance, but today its magnitude gives reason to fear that it could be harmful to health. Some epidemiological studies give proof that air pollution in general, and especially its *particle phase*, has an influence on morbidity as well as mortality of the pouplation[1,2].

Hygienic significance of particulate matter. Out of the great number of various immissions, we shall therefore consider the *particle phase* only. This can be divided into *sedimentary dust* and actual suspended *particulate matter*. Contrary to sedimentary dust, particulate matter comprehends the fine particles which penetrate into the human lung, i.e. the so-called *lung-penetrating* fraction. When dust is inspired, its effect is mainly determined by its composition. Here, the original *chemical structure* of dust, as well as its *adsorbability*, plays a decisive part.

Atmospheric dust consists mainly of *soot* and *mineral components*. However, depending on its origin, dust can also contain *traces*, such as lead, iron, cadmium, and asbestos. In inhabited areas, lung-penetrating dust consists mainly of soot, i.e. of submicroscopical agglomerations of particles – mostly carbon – having absorbing power due to the large surface area. Consequently, soot particles can be bearers of substances harmful to health.

Suspended particulate matter is of special significance from the hygienic viewpoint; because of high adsorbing power it may lead to heavy concentrations of pollutants

Fig. 2. Monthly mean values of particulate matter and 3.4 benzopyrene immissions. Average values of 5 measuring points in Zurich-City (without Uetliberg).

[1] W. Winkelstein, S. Kantor, E. W. Davis, C. S. Maneri and W. E. Mosher, Arch. envir. Hlth. *14*, 162 (1967); *16*, 401 (1968).

[2] L. D. Zeidberg, R. J. M. Horton and E. Landau, Arch. envir. Hlth. *15*, 225 (1967).

locally. Therefore, in the respiratory tract a locally increased effect of adsorbed substances is possible in the vicinity of a deposited particle. Furthermore, soot enhances the chemical reactions between various components of air pollution. Photochemical reactions between hydrocarbons and oxides of nitrogen are examples which lead to the so-called 'smog'. Solar radiation can thus be reduced by up to more than 50%. Therefore, particulate matter has a special significance even before human contact.

Sulphur oxides, as well as *polyaromatic hydrocarbons* (paHC), to which cancerogenic *Benzo(a)pyrene* (BaP) belongs, are among the most important soot particles adsorbing components. Among HC, BaP holds the position of an indicating substance, because BaP is chemically the most stable and therefore most frequent of the biologically very active paHC[3]. PaHC originate from the same conditions as soot, viz. through incomplete combustion of organic substances[4]. Consequently, heating installations, combustion motors and special industrial processes are the most important emission sources of BaP.

In the measurements carried out in Zürich, immissions of suspended particulate matter and benzo(a)pyrene were ascertained representatively at monitoring point with varying environmental character. Simultaneously, the various air pollution sources (heating installations, motor vehicles, industry) were proportionately assessed.

Measurements in Zurich. In the years 1971/72 particulate matter was measured in Zurich at 6 different monitoring points. The so-called *LIB-procedure* was applied, which had formerly been used by the 'Landesanstalt für Immissions- und Bodennutzungsschutz des Landes Nordrhein-Westfalen', particularly in the Ruhr region. This procedure permits the determination of average concentrations of particulate matter over 24 h and the collection of particulate matter quantities of 50 to 100 mg for analytical purposes (Figure 1).

[3] E. CLAR, *Polycyclic Hydrocarbons* (Academic Press, London 1964).
[4] K. H. HOMANN, *Russbildung in Kohlenwasserstoffflammen* (Arbeitstagung Schwebestofftechnik, Battelle-Institut, Genève 1971).

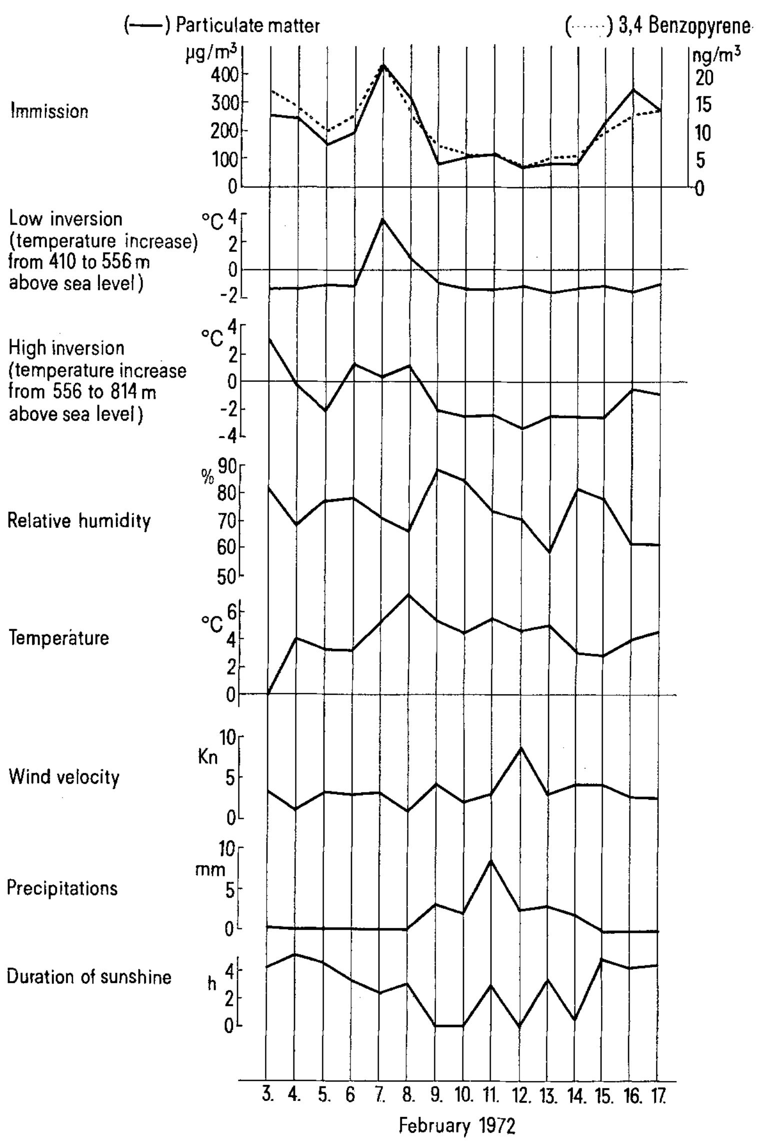

Fig. 3. Relations of immissions with meteorological parameters.

Table I. Measurements of suspended particulate matter and 3.4 benzopyrene

Measuring points	Particulate matter concentration		3.4 Benzopyrene concentration	
	Yearly mean value (μg/m³)	Extreme values 24 h (μg/m³)	Yearly mean value (ng/m³)	Extreme values 24 h (ng/m³)
Industrial zone				
Escher-Wyss	128	21–484	5.3	0.5–21
Congested squares				
Paradeplatz	160	24–503	5.5	0.5–24
Albisriederplatz	181	26–605	7.7	1.5–27
Residential areas				
Untere Zäune	125	26–460	6.4	0.5–28
Triemli	100	18–385	4.1	0.3–19
Recreation zone				
Uetliberg [a]	approx. 50	14–114	approx. 2.5	0.3– 9

6 measuring points in Zurich, measuring period April 1971 to March 1972. [a] Measuring period September 1971 to March 1972.

Every single dust sample was analyzed for benzo(a)-pyrene (BaP). A fluorescent spectrophotometric procedure[5] was used, which makes it possible to obtain selectively, without chromatographic separation, BaP in the cyclohexane extract of particulate matter by measuring fluorescent intensity in 7 different combinations of exciter and analyzer wave lengths and taking into consideration influences of interference.

The monitoring points were different as regards the immediate surroundings. They were divided into industrial zone (Escher-Wyss), congested squares (Paradeplatz, Albisriederplatz), residential areas (Untere Zäune, Triemli) and recreation zones (Uetliberg). On 16 days per month, 24-hours mean values were gathered.

Results. As can be seen in Table I, the *yearly mean values* for particulate matter concentrations were highest at congested squares (Paradeplatz and Albisriederplatz). The industrial zone (Escher-Wyss) and the old town residential areas (Untere Zäune) were in the intermediate position. The more modern residential area (Triemli) and especially the recreation zone (Uetliberg) showed lower values. The yearly mean values for 3.4 benzopyrene immissions were similarly proportioned, with exception of those at the old town measuring point. There the value was greatly influenced by increased BaP content, especially during the heating period.

The *monthly mean values* of particulate matter and BaP immissions for 1971 and 1972 are shown in Figure 2. It is evident that the immissions during those 2 years showed a pronounced course. In winter they were considerably higher than in summer; the highest particulate matter concentrations over 24 h ocurred in winter (600 μg/m³), the lowest in summer (20–30 μg/m³); a maximum value for 3.4 benzopyrene was measured in winter (28 ng/m³). ($1 \text{ ng} = 10^{-3}$ μg.)

In winter, particulate matter immissions were about 2.5 times higher than in summer, and the 3.4 benzopyrene immissions were about 5 times as high. These differences were more marked in residential areas than on congested squares. One of the principal sources of emission of particulate matter in winter is the *heating installations*. It often happens that due to bad maintenance, the combustibles are not burnt completely and therefore great quantities of soot are expelled. A quantification of seasonal and local differences, however, was not possible, as the atmospheric inversion conditions which occur more frequently in winter also lead to an increase of immissions.

Influence of atmospheric conditions. The influence of atmospheric conditions was of special interest for the relations between immissions and emissions. Based on

[5] M. Waibel, Dissertation Nr. 5107, ETH Zürich (1973).

Table II. Measurements of suspended particulate matter (LIB-procedure)

Location	Yearly mean values (μg/m³)					
	Average	Individual measuring points				
Duisburg	257	227	254	291		
Oberhausen	222	222				
Bottrop	206	206				
Gelsenkirchen	199	186	211			
Dortmund	198	198	198			
Essen	181	138	176	189	220	
Bochum	181	181				
Castrop Rauxel	167	167				
Zürich	139	100	125	128	160	181
Frechen	129	129				
Horrem	125	125				
Hürth	120	120				

Number of measuring days per year: Zurich 192, Germany 156.

correlation computations with daily mean values of 5 measuring points during the test period from January 1971 to April 1972, and the meteorological data representative for Zurich, the following can be said: With greater wind speed and higher atmospheric precipitations, the immission concentrations decreased. In atmospheric inversion conditions, immissions increased greatly. The lower the air temperature, the higher were the immissions measured.

It is obvious that these meteorological parameters had a decisive influence on immission concentrations, as daily mean values could be observed which varied greatly. Figure 3 shows these findings. Here the course of immission concentrations of particulate matter and BaP during 15 days is compared to the course of meteorological parameters showing a statistically guaranteed relation with the immissions. For this graph a month with particularly great variations of immissions and atmospheric conditions was chosen. It clearly shows that *above all the inversions decisively influence immission concentrations* (maximum value February 7, 1972).

The influence of other parameters – such as wind speed, atmospheric precipitations, air temperature – cannot be seen clearly in Figure 3. The statistical elaboration of the data gathered in 235 measuring days resulted, however, in unequivocal relations between immissions and these parameters. An influence of relative air humidity, as well as duration of sunshine, on immissions of particulate matter could not be observed. On the other hand, immissions of BaP increased with great air humidity. With increasing sunlight, the content of these components in particulate matter decreased.

Comparisons with measurements in other countries. In Table II the measurements of Zurich are compared to those of some German towns[6]. Yearly mean values of particulate matter immissions of a total of 5 measuring points in Zurich and 18 in Germany were available.

It is obvious that the average concentrations of suspended particulate matter in Zurich were in general lower than those in the industrial agglomeration centres in the Ruhr area. However, when comparing individual measuring points, it can be observed that in Germany 6 measuring points showed lower and 12 showed equal or higher yearly mean values than those of Albisriederplatz in Zurich. Lower yearly mean values than those of Paradeplatz occurred only at 4 German measuring points. At the measuring points Escher-Wyss, Untere Zäune and Triemli the yearly mean values were the same or lower than those of the Ruhr area with the smallest immission concentrations.

Table III. Measurements of suspended particulate matter (High-Volume-Air-Sample)

Cattanooga	180
Philadelphia	170
Detroit	143
Boston	134
Nashville	128
Memphis	113
Washington	104
Houston	101
Worcester	93
Springfield	70
Greensboro	60
Miami	58

5-year mean values 1961 to 1965 in µg dust/m³.

In Table III, 5-year mean values of some American towns are shown. Of a total of 60 American measuring points, only 3 had lower values than those of the limiting values (primary standard) of 75 µg/m³ [7]. When comparing measured values of the various towns, it must, however, be taken into consideration that measuring methods and location of measuring points cause certain differences.

Significance of immissions of suspended particulate matter. Epidemiological studies in the United States (cited in [8]) have shown that a relationship exists between suspended particulate matter immissions and morbidity as well as mortality of the population. Strangely enough, no dependence between suspended particulate matter content of the air and lung cancer occurred; but, a connection with mortality due to stomach cancer could be observed. The influence of air pollution on mortality due to diseases of the respiratory tract was particularly marked: it triplicated from the degree with the lowest (< 80 µg dust/m³) to the degree with the highest (> 135 µg/m³) air pollution.

Whether these unwholesome effects can only be attributed to the benzo(a)pyrene content of particulate matter can hardly be ascertained on the basis of epidemiological studies alone. This would not only require knowledge of the effect of particulate matter, but an additional differentiation by components adsorbed in particulate matter. It can, however, be accepted that the sum of various substances, especially polyaromatic hydrocarbons (paHC), contribute to the carcinogenic effect of particulate matter.

Among these paHC, benzo(a)pyrene has the position of an indicating substance, as it is a biologically very active, chemically stable and therefore a frequently occurring component of air pollution. The position of an indicating substance is furthermore indicated, as it originates together with other polyaromatic hydrocarbons and soot from incomplete combustion of organic material.

The particulate matter and 3.4 benzopyrene concentrations measured in Zurich – especially on some days in the winter months – are partly very high. Based on the epidemiologic studies mentioned, health injuries must be expected here too. Therefore, *it is necessary to reduce emissions by means of well-planned measures: heating systems have to be more closely supervised; in winter months rooms should not be overheated; new housing developments should be provided with a central heating system in an adequate location; in new buildings more attention should be paid to insulation; furthermore, effective laws and controls on motor vehicle exhaust gasses should be put into force.*

Zusammenfassung. Mittels LIB-Verfahren und fluoreszenzspektroskopischer Analyse wurden während mehreren Jahren Immissionsmessungen von Schwebestaub und 3,4-Benzpyren in der Großstadt und Umgebung an charakteristisch divergenten Meßstellen durchgeführt.

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[6] Schriftenreihe der Landesanstalt für Immissions- und Bodennutzungsschutz des Landes Nordrhein-Westfalen *23* (1971).

[7] H. U. WANNER, *Grenzwerte der Luftverunreinigung.* NZZ, Nr. *123*, 13. März 1972.

[8] E. GRANDJEAN, Schweiz. med. Wschr. *102*, 1889 (1972).