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MONAT-84: EXPERIMENTAL STUDY FOR THE NEEDS OF AIR POLLUTION CONTROL IN CRACOW, POLAND

A large-scale experimental study on the monitoring of atmospheric air over the city of Cracow was carried out in February, 1984. The study is referred to as MONAT-84. This paper includes a detailed account of how the experiment was designed, and a discussion of the results obtained.

1. INTRODUCTION

It is a well-established fact that the agglomeration of Cracow belongs to those regions of Poland where the highest air pollution levels are measured. Most of the pollution comes from local sources, specifically from the adjacent large ironworks. But the area of Cracow receives considerable pollution loads from the Upper-Silesian Coal Region. A further contributing factor is the location of the city in the valley of the Vistula which accounts for the frequent occurrence of temperature inversion. Temperature inversion combined with light wind creates favourable conditions for the persistence of pollutants in the atmospheric air over Cracow.

Cracow and Nowa Huta with a population of 800,000 ranks third in the total number of Polish cities and towns. Cracow is also a treasury of inestimable monuments and objects of Polish history and culture and has been listed by UNESCO among the most valuable monuments of the world culture heirloom.

Having these in mind, the decision was made to establish an efficient monitoring system. The first step consisted in a large-scale experiment (referred to as MONAT-84) which was

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carried out in Cracow from 1 to 29 February, 1984. The objective was to verify a mathematical model of air pollutants dispersion for urban agglomerations. The model of interest (referred to as URFOR) is a Gaussian model which incorporates dry deposition, rain scavenging and transformation of pollutants, as well as upper and lower temperature inversions. The model also includes the coefficients of atmospheric diffusion determined by Nowicki. The coefficients describe the effect of emitter height and ground surface roughness. Testing and calibration of the model involved appropriate selection of empirical coefficients in order to match the calculated and measured concentrations.

The scope of the experiment may be itemized as follows:

- 1) determination of the emitted sulphur dioxide volume for significant emission sources (industry, heat and power generating plants, kitchen ranges and house-heating) in the city of Cracow and immediate vicinity;
- 2) identification of meteorological factors favourizing the occurrence of particularly high concentrations of air pollutants;
- 3) appropriate location of meteorological stations representative of compact settlement areas of Cracow;
- 4) site selection for measuring points representative of air monitoring;
- 5) verification of measuring methods and procedures.

2. DESIGN OF EXPERIMENT

The model involved sulphur dioxide as a testing substance. In the region of interest, sulphur dioxide belongs to the most hazardous pollutants. The volume of emission is satisfactorily recognized, and the methods of immission measurements are successfully practiced. The measurement of sulphur dioxide covered an area of approximately 200 km² was performed by three methods:

- 1) continuous recording by automatic gauges at four points situated in the city centre,
- 2) recording of daily averages at 35 receptors,
- 3) short-range (30-minute) recording at 25 receptors.

Short-range measurements were carried out every day from 8:00 to 8:30 a.m. and from 1:00 to 1:30 p.m. Every day measurements were also performed for the concentration of fine dust particles (at 35 receptors) and for dust fallout deposition (at 110 receptors). Chemical analyses carried out each day amounted to about 120. The daily mileage for service cars totalled 1500 or so kilometers.

Emission of sulphur dioxide was determined twice a day for about 120 major emitters (industry, heat and power generating plants, area sources; the latter being particularly frequent in the city centre). The emission rate was related to the hour of the day, to air temperature and wind velocity. Area sources have been specified and divided into 250 × 250 m squares and 500 × 500 m squares in the city centre and in the remainder, respectively. The total

number of area sources amounted to 225. The experiment included all significant industrial and municipal sources of sulphur dioxide emissions in the radius of 150 km from Cracow. The overall number of sources involved in the verification of the model approached 600.

Another set of measurements comprised meteorological factors. Conventional on-ground recording of wind direction and wind speed, air temperature and precipitation volume was carried out at 10 stations in the area and vicinity of Cracow. The vertical profile of wind speed and wind velocity was recorded at 4 points, whereas that of air temperature (radiosonde) at 2 points.

Non-conventional methods were used for the measurement of other important parameters. Thus, the thermal structure of atmospheric air was determined by sodar and from an airplane flying over the area of interest at various heights. Plume rise from the heat and power generating plant was measured by lidar, whereas the behaviour of the sulphur dioxide carrying plume from the ironworks was determined by a Barringer (Canada) correlation spectrophotometer.

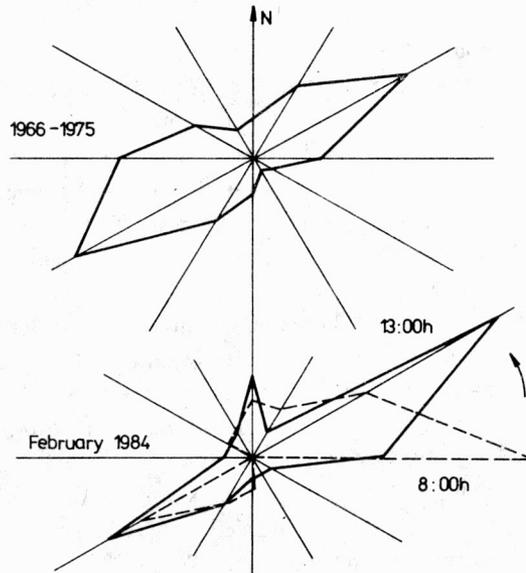
The experiment — supervised by Dr. Bronisław Kamiński, the director of the Environmental Pollution Control Department of the Municipality of Cracow — involved some 300 individuals and 15 organizations from Cracow and Warsaw.

3. RESULTS

MONAT-84 yielded a great number of valuable experimental data for the verification of the URFOR diffusion model, i.e. a set of 58 distributions of 30-minute concentrations and a set of 29 distributions of 24-hour concentrations of sulphur dioxide. The results of verification are reported elsewhere. MONAT-84 gave, moreover, valuable information on the specific meteorological conditions influencing the city of Cracow, as well as on the environmental impact of sulphur dioxide emission.

Figure 1 shows some meteorological parameters for February, 1984. As shown by these plots, the wind rose of that period is similar to the many-years' rose. It is interesting to note that there was a high frequency of occurrence of easterly winds in the morning hours; during afternoon and evening, they usually changed to north-easterly. In the period of interest, there was only one event of north-western wind which brings an inflow of pollution from the Upper-Silesian Coal Region.

Stability categories (lower temperature inversions) were observed during morning measurements only. Upper temperature inversions, which accounted for some 50% of events in the morning hours, were subject to diffusion during the day. Their level averaged between 330 m (in the morning) and 480 m (in the afternoon). It is worth noting that upper temperature inversions were always associated with easterly winds. Lower temperature inversions showed no correlation with wind direction, but they were always associated with light winds and poor cloud cover. Sulphur dioxide concentrations measured under these conditions in the city centre were the highest — they amounted to 1.0 mg/m^3 . It was also found that the sulphur-dioxide



Frequency of atmospheric stability categories (‰)

Time	B	C	D	E	F
8:00-8:30 h	—	3.4	79.4	13.8	3.4
13:00-13:30 h	3.4	41.6	55.0	—	—

upper temperature 8:00-8:30 h, 41.4‰; inversion 13:00-13:30 h, 17.2‰

Fig. 1. Some meteorological parameters for Cracow (February 1984)

Rys. 1. Niektóre dane meteorologiczne Krakowa (luty 1984)

carrying plume from the ironworks had a significant contribution to the air pollution level in the city of Nowa Huta and did not affect the compact settlement area of the city centre of Cracow because it became dissipated before reaching it. The main contributor to the pollution load over Old Cracow is the emission coming from small area sources. Irrespective of wind direction, high concentrations of sulphur dioxide were measured throughout the Old Cracow District where houses are predominantly fired with coal or coke. This is an indication that the need of substituting stove heating by electric or gas heating system has become urgent.

Another interesting phenomenon observed in February, 1984, was an intensive acid smog occurring on frosty days with easterly winds (from the ironworks). On those days very high concentrations of dust particulates were measured in the city centre. The presence of a large number of alkaline dust coming from the ironworks created favourable conditions for the transformation of sulphur dioxide to sulphate ion. The phenomenon, which is typical of the winter months, calls for further investigation, specifically for the measurement of sulphuric

acid aerosol, a highly toxic smog component. An indication of how fast the transformation of sulphur dioxide to sulphate ion runs is the fact that the best agreement between calculated and measured distributions has been obtained by assuming a half-life of about 120 minutes.

The MONAT-84 experiment provided large sets of data which made it possible to determine the field of the lower wind in areas with compact settlement. These data also enabled appropriate siting of the meteorological station to work for the purpose of monitoring. The experiment showed, moreover, that the need of performing routine radiosondes of the atmospheric air over the city of Cracow had become urgent. There were established the location of radiosonde, as well as the number and situation of receptors for the monitoring system.

Summing up, MONAT-85 yielded valuable and important data on the actual state of the atmospheric air over the Cracow agglomeration. It was also helpful by providing information on how to organize the monitoring system and make it cooperate with the verified mathematical model enabling short-range forecast of air pollution hazards.

The experience gained during the MONAT-84 experiment may be of utility to those who organize similar monitoring systems for other industrialized urban areas exposed to high pollution loads.

EKSPERYMENT BADAWCZY W ZAKRESIE OCHRONY ATMOSFERY MONAT-84 W KRAKOWIE

Przedstawiono organizację i najważniejsze wyniki eksperymentu związanego z MONitoringiem ATmosfery (MONAT). Eksperyment ten wykonano w lutym 1984 r. w Krakowie.

MONAT-84 IN KRAKAU – EINE EXPERIMENTALE STUDIE IM GEBIET DER REINHALTUNG DER LUFT

Das hier besprochene Experiment wurde im Februar 1984 in Krakau durchgeführt. MONAT-84 ist eine Anspielung auf die englische Bezeichnung „Monitoring of Atmosphere“. Die wichtigsten Ergebnisse dieses Monitoring-Verfahrens werden besprochen.

ИССЛЕДОВАТЕЛЬСКИЙ ЭКСПЕРИМЕНТ, КАСАЮЩИЙСЯ ОХРАНЫ АТМОСФЕРЫ В КРАКОВЕ (МОНАТ-84)

Представлены организация и важнейшие результаты эксперимента, связанного с "МОНиторинг АТмосферы" (МОНАТ). Эксперимент был проведён в феврале 1984 года в Кракове.