DESIGN AND CONSTRUCTION OF A COMPUTER CONTROLLED AUTOMATIC SEQUENTIAL RAIN SAMPLER

Bulent Oktay Akkoyunlu[1], Murat Dogruel[2], Mete Tayanc[3], Ilker Oruc[4]
[1]Marmara University, Department of Physics, Istanbul, Turkey
[2]Marmara University, Department of Electric and Electronics Engineering, Istanbul, Turkey
[3]Marmara University, Department of Environmental Engineering, Istanbul, Turkey
[4]Kirklareli University, Vocational College of Technical Sciences, Kirklareli, Turkey
Correspondence to: Bulent Oktay Akkoyunlu
E-mail: bulentoktay@marmara.edu.tr

ABSTRACT

The preliminary goal of this study was to design, construct and apply a new automatic sequential precipitation sampling instrument. The proposed sequential sub-event sampler was designed in two sections: mechanical and electronical sections. The mechanical part includes a series of 100 mL sampling bottles on it, and a metallic body. The electronic part is composed of digital and analog sensors, various electronic material and a computer as the main controller of the system.

Commands generated by the computer control the system, and the sub-event sampling period and the volume can be adjusted. Besides the volume and time controlled sampling, intelligent control and sampling is possible by developing adequate algorithms. Since the system consists of automatic sensors that can be controlled by the computer, anthropogenic errors in sampling are expected to be kept at minimum. The proposed instrument is open to development and additions can be easily made.

The application phase includes collection of sequential precipitation samples, their analysis and an attempt to determine the sources of environmental pollution. The developed equipment was used to collect samples for five rain events that took place on 7 September 2007. The samples were analyzed for Na^{+}, Mg^{2+}, Ca^{2+} and K^{+} to obtain the temporal variation of the chemical composition during the precipitation event.

Biotechnol. & Biotechnol. Eq. 2013, **27**(3), 3890-3895

Keywords: precipitation, sequential rain sampling, rain chemistry, ion concentrations

Introduction

Atmospheric deposition is the process by which airborne particles and gases are deposited on the earth surface either through precipitation, known as wet deposition, or through settling, impaction, and adsorption, known as dry deposition. With regard to the measurement of any chemical constituent in the atmosphere, the four main sampling methods used to collect the atmospheric deposition are wet only, dry, bulk, and sequential rain samplings.

Wet only and dry sampling were generally carried out together using the automatic sampler device which allows the collection of both wet and dry (dust) deposition as separate fractions. The device is equipped with a motor-driven cover that exposes one collector for dry deposition only during dry weather and another for wet deposition only when it is raining. Wet deposition collections have been widely carried out in many areas with the aim of finding the sources of atmospheric pollutants scavenged by rain drops, investigation of acidity and temporal variations and statistical classification of chemical constituents in the rain (1, 17, 18).

Dry deposition includes only particulate matter such as wind-blown particles, gas-to-particles conversion, and sea salt particles. Erisman et al. (9) provided an overview of the development of deposition monitoring stations and the main results of the three core sites. Furthermore, the results of the development of a low-cost monitoring system are presented. Because of the high costs associated with technical measurements of airborne contaminants, alternatives have been developed (19). For monitoring heavy-metal airborne pollution, moss species are especially suitable due to their high cation-exchange capacity (5). The atmospheric pollution during a 3-year period (2003–2005), assessed by mosses, and following the European Moss Survey 2005/2006, in Bulgaria was presented (19).

Bulk deposition includes both wet deposition and dry deposition that may fall into a collector which is continually kept open to the atmosphere. Since bulk precipitation samplers are open at all times, an unknown fraction of gaseous and particular matter can be collected along with the rain water. Bulk deposition chemistry is very sensitive to local contamination from wind-blow dust, birds and insects, which is why the choice of the sampling site is of crucial importance. If local contamination is regarded, bulk deposition will probably better approximate what actually falls on the soil surface than wet deposition would (8). Akkoyunlu et al. (2) introduced the differences between wet and bulk deposition chemistry. Cape et al. (6) described a simple battery-powered modification to a standard bulk sampler that allows separate measurement of the deposition to the funnel surface and wet deposition by washing the funnel surface.

Sequential samplings are carried out by collecting the rain water automatically or manually into the sampling cases sequentially during one single rain event only. Sequential sampling has some advantages and disadvantages in comparison to the other sampling strategies; wet-only, dry, and bulk deposition samplings. An advantage of sequential sampling is that more detailed information is obtained about one rain event, since more samples are collected. A disadvantage of this type of sampling is that it is more costly owing to the more expensive sampling device and the greater number of samples that need to be analyzed. Manual collection in all sampling methods is least expensive in terms of equipment costs, but it requires a person to change the collection vessel at the appropriate times.

In this study, a computer-controlled sequential rain sampler with two main components: mechanical and electronic, was designed and tested with a rain event which occurred on 7 September 2007. The Mechanical part includes a rain gauge, a series of solenoid valves, 100 mL polyethylene sampling bottles and a metallic body. The electronic part is composed of sensors, various electronic components, ICs, and relays. A computer is utilized as the main controller of the system. Commands generated via the MATLAB programming language control the system, and the sequential sampling period and volume can be modified. Besides the volume and time controlled sampling, intelligent control and sampling is possible by developing adequate algorithms. Since the system consists of automatic sensors that can be controlled by the computer, anthropogenic errors in sampling are kept at minimum. This study was previously presented for discussion at an international scientific conference SGEM (4), where a brief presentation was given.

Materials and Methods

Mechanical description

The mechanical part contains two parts as an inner and outer body, made up of stainless steel sheets in the shape of a cylinder. The inner body is covered by the outer body, which can be moved up and down and which can be latched to the inner body (**Fig. 1**). The entire sampler body is weatherproof and vent holes prevent the moisture from increasing inside. The headpiece of the outer body is also used as a funnel, called the outer funnel, for collecting rain water. Another funnel, called the inner funnel, much smaller than the outer one, is placed on the inner body in order to collect the rainwater coming from the outer funnel and then drain to the rain gauge. The rain gauge consists of two solenoid valves and a cylindrical plastic tube; the volume between these valves is 5 mL (**Fig. 1**).

While the tube fills, the upper valve opens and the lower valve closes. When the tube used for a reservoir fills, short contact is provided between the sensors attached to the upper and lower sides of the tube so the upper valve of the rain gauge closes and the lower valve opens electronically. Subsequently, all the rain water drains out so that the upper valve opens and the lower one closes. This process is repeated until the rain stops. Twenty-one solenoid valves and polyethylene sampling bottles below each solenoid valve are mounted in such a way that they are at different heights in the inner body and are linked together by polyethylene tubes. Initially, all solenoid valves are open and the rain water in the rain gauge drains through the first solenoid valve and into the first sampling bottle on the inner body of the sampler device.

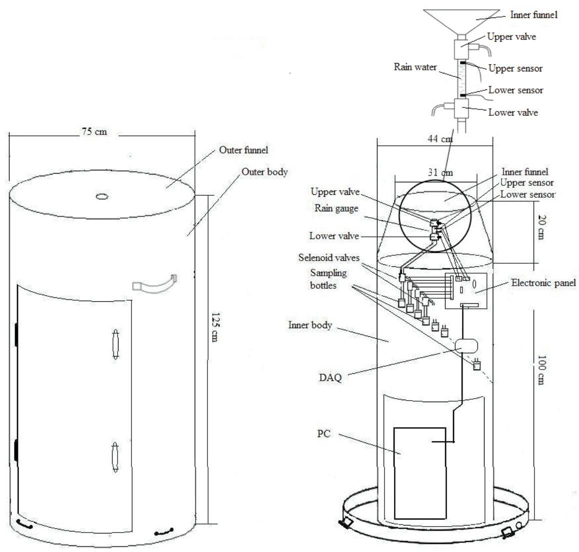

Fig.1. Schematic diagram of the automatic sequential rain sampler and the rain gauge.

This is repeated several times (the number of repetitions can be optionally changed using the programming language MATLAB) and then the first solenoid valve above the first sampling bottle is closed by a current-controlled and electronic device. After completing the sampling for the first sequential event, the first solenoid valve is closed and subsequently, the rain water drains through the second solenoid and then into the second sampling bottle mounted below of this solenoid valve, because of the level difference. This sequence continues until the rain stops, or until the last bottle (21st bottle) is filled. If there is no rain in any of the sequential samplings for a long time, the valve linked to the sampling bottle for this sub event is closed by means of the developed MATLAB algorithm. Hence, as soon as it starts raining, the next valve opens and the rain water flows into the next sampling bottle. This strategy does not allow rain water from different sources or systems (cyclones, fronts etc.) to be mixed in one and the same sequential sampling bottle. The software developed using the MATLAB programming language completely controls the process and transfers data relevant to the time and the level of the rain water in the sampling bottles through an input/output unit into a file. The data stored in this file can be used for calculating the rain intensity. The device can be programmed to collect the sequential samples in a variety of ways with the commands in the algorithm, to sample either by volume or by time. As the number of openings/closings of the solenoid valve placed below the rain gauge tube can be changed via the algorithm, the volume of the rain water of sequential samplings can be adjusted by changing the related commands. In this way, the sequential samples can be collected as fixed volumes. Furthermore, the duration of sequential samplings can be adjusted by changing these same commands in the algorithm so that sequential samples can be collected at fixed time intervals.

Software description

Data acquisition card (DAQ) was used in order to process the signals that measure the physical condition of the device and convert the electrical signal into digital numeric values that can be manipulated by the computer. Typically, DAQs digitize analog waveforms for processing the signal. Software is needed to maintain DAQ hardware operations. The algorithm to run the rain collection system is provided in **Fig. 2**. When the system is started, all the valves are shut to make sure the system initiates correctly. Initially, the maximum time and maximum volume of the bottles are set according to the desired operation conditions. Furthermore, selection of the bottles which will be used for sampling can be done at this stage. The user can change these parameters before running the system.

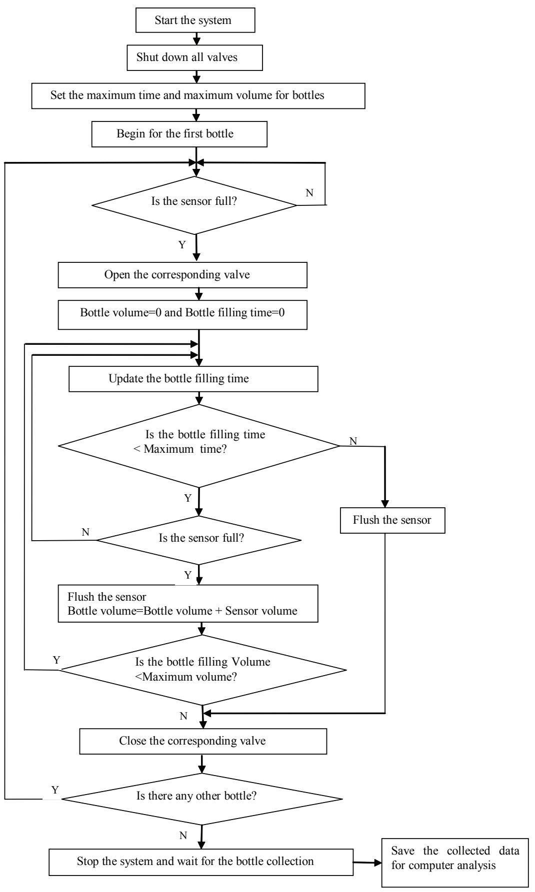

Fig. 2. Software flowchart.

The algorithm starts with the first selected bottle and the system waits at the state until the next portion of rain fills up the rain gauge. Then the corresponding valve is opened so that the rain water collected in the rain gauge can be transferred to the selected bottle. First, the bottle volume and the bottle filling time are set at zero. As time passes, the bottle filling time is updated to make sure the maximum time allocated is not over. If the time is already over, the water remaining at the sensor is immediately flushed into the corresponding bottle and the process ends for this bottle. If the time is not over yet, the sensors in the upper and lower side of the rain gauge tube control whether it is full or not. If it is full before the allocated time is over, the rain gauge is flushed to the corresponding bottle, and the bottle volume is updated accordingly. If the maximum volume for this bottle is not reached yet, the rain sample collection for this bottle continues; otherwise, the process is terminated for this bottle. The same process is repeated for the next bottle until all bottles are processed. As seen from the algorithm, there are two criteria to end the processing of a bottle: due to the time limit or the volume limit. These limits can be easily adjusted by the user. If one does not consider any time limit and would like to run the system according to the volume limit only, i.e. the bottles to be processed till filling up, then the maximum time setting could be chosen to be very large (e.g. days).

Hardware description

The hardware part consists of a PC running the software, a DAQ device to interface with the PC, and a control card to drive the solenoid valves and collecting sensor signals. The block diagram of the system is given in **Fig. 3**. The DAQ used is a USB controlled device providing various Analog I/O ports working up to 50 KHz, and various Digital I/O ports connected to the control card. The DAQ gets its power from the PC and for the remaining part of the system a power supply of 17 V and 3 A is used. The system can support up to 32 solenoid valves for rain collection. The rain gauge consists of 2 solenoid valves, one for taking water into the measuring tube and one for discharging the measured water together with a digital water level sensor.

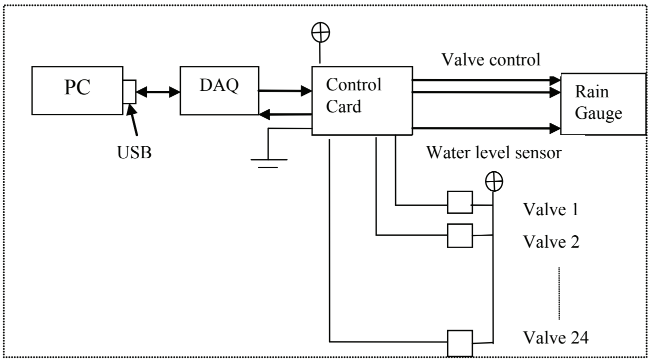

Fig. 3. Block diagram of the system.

The electronic diagram of the control card is provided in **Fig. 4**. An optoisolator chip (IC1) is used to isolate the DAQ signals from the power system for safety. Four-bit serial input to the cart is used for control and 1-bit output is used for sensor data acquisition. An inverter/buffer chip (IC2) is used for signal conditioning. Two 8-bit serial-in parallel-out shift registers (IC3 and IC4) are used to get the digital input signals from the DAQ. Eight-bit digital outputs of the shift register IC3 are then connected to two 4x16 multiplexer chips (IC5 and IC6). Therefore, a total of 32 bits are provided as digital outputs which are connected to driver chips (IC8 to IC11) to control the solenoid valves for rain collection. Just one of the possible 32 valves can be turned on at any time by selecting the serial digital inputs correspondingly. The other shift register (IC4) outputs are directly connected to a driver chip (IC7) to control an independent 8-bit output. These signals control the relays which can provide independent power outputs for various purposes. Two of these relays are used for the rain gauge solenoid valves. The rain gauge water level sensor signal, on the other hand, is sent back to the DAQ through the optoisolator chip (IC1) after conditioning with a transistor circuit.

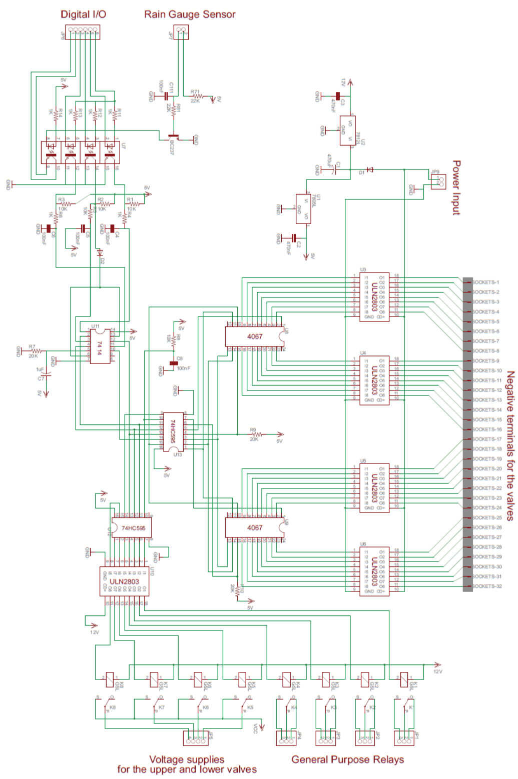

Fig. 4. Electronic diagram of the control card.

Results and Discussion

To establish the dimensions and sources of various precipitation types taking place at different regions and dates, the design and development of the sequential precipitation sampling instruments and analysis techniques are becoming increasingly important. Krupa (12) categorized the sequential sampling strategies based on five basic approaches: grab sampling, time-related grab sampling, time-weighted sequential sampling, intensity weighted sequential sampling and continuous monitoring. Sequential rain samplers were grouped by Robertson et al. (16) into four basic categories: 1) manually segmented; 2) linked collection vessels; 3) automatically segmented; and 4) continuous. The authors reviewed the sequential sampling techniques and applications to collect precipitation. Chemical data for samples collected by an intensity-weighted sequential sampling device from October 1976 to April 1978 showed that intensity-weighted sequential sampling can be a viable technique for monitoring the rapid changes in precipitation chemistry within a storm (16).

An automatic sequential precipitation sampler which consists of mechanical and electronic parts was designed and constructed. The sampler device can be programmed to collect in a variety of modes, to sample either the volume or time, record all relevant timing and operational status data. The sampling volume or sampling time for each sequential rain event can be adjusted by changing the algorithm. Such a sampling device enables the researchers to investigate the variation of composition during the rain events associated with the atmospheric condition like rain intensity, weather temperature, pressure etc. The sampler was designed in such a way that it can collect rainwater in up to 21 bottles. The number of sampling bottles can be increased by adding the valves and changing the algorithm without change in the electronic design of the rain sampler. The working process of the constructed sequential rain sampler was tested in a rain event that took place on 7 September 2007 and the device was subjected to a short evaluation of the contaminant concentration in the sequential samplers collected in this rain event as a function of rain intensity and duration. **Fig. 5** illustrates the air mass back-trajectory for this rain event obtained by the NOAA HYSPLIT trajectory model (7). The back-trajectory was calculated at every 6 h intervals for a 24 h total period. The rain event, which was of marine source, was associated with the air mass coming from the Middle Mediterranean Sea and the low pressure system trajectory reached Istanbul by migrating over South Greece and the Aegean Sea. It was characterized with a minimum sea level pressure value of 1004 mb and decrease in temperature from 21 °C to 17 °C.

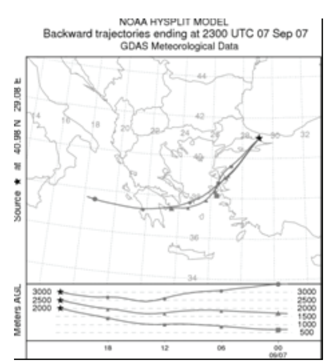

Fig. 5. NOAA Hysplit Model backward trajectories.

Before sampling the rain event, the device was artificially tested several times. The funnel of the instrument was exposed to distilled water in such a way that all bottles were filled up to nearly 20 mL and it was observed that the rain sampler device does not contaminate the water. Next, these blank samples were analyzed for Na^+, Mg^{2+}, Ca^{2+}, and K^+ ions. Sequential samples were taken for that single rain event together with the presence of online satellite images. Just before the approach of the low pressure system, the rain sampler device was located at a place where it would collect precipitation samples. Prior to the experiment, the funnel and bottles used for sub-event sampling were rinsed with distilled water, soaked in a 5 % nitric acid bath and then rinsed again with distilled water and dried. After the experiment, the precipitation sampling bottles were removed from the sequential rain sampler body and brought to the laboratory. Samples were filtered and stored in pre-cleaned polyethylene bottles in the refrigerator at 4 °C prior to chemical analysis. The concentration of the main cations (K^+, Ca^{2+}, Na^+ and Mg^{2+}) was determined by Hitachi-180-80 atomic absorption spectrophotometer (AAS).

The device was programmed to collect the sequential samples with a fixed volume (50 mL). Twenty sequential samples were collected during the rain event. Sequential experiments give information about temporal variation of the chemicals, scavenging processes, and comparison of the initial and the final stages of the rain events (3, 11, 13, 14).

Complete chemical data is needed from individual storms to evaluate the intensity related scavenging (16). Gatz and Dingle (10) developed a sequential rain sampler that collects up to 70 samples from 35 mm to 70 mm of rain and can determine the sample time accurately. Each sample had a volume of 500 mL to 1000 mL, which represented 0.5 mm to 1.0 mm of rain. Raynor and McNeil (15) designed a timer actuated device. Time periods were preset but adjustable between sampling runs. Luo (13) investigated rainwater collected by sequential sampling on a time and volume basis for a period as short as possible in order to maintain the meteorological conditions constant. Varying patterns of sequential cumulative wet-deposition fluxes of soluble chemical species and the elements in insoluble materials with rain duration were examined in that study (13). Another study presented the interrelationship among the chemical composition parameters in a sequential sampler and atmospheric variables for four storm events that were sampled manually in Istanbul (3).

Since the aim of our study was to design, construct and apply a rain sampling device, sequential rain samples belonging to only one rain event were collected and analyzed with the aim of testing it. The variation of the concentrations of the ions found in this experiment and the rain intensities are illustrated in **Fig. 6**. The mean concentrations of Na^+, Mg^{2+}, Ca^{2+} and K^+ were calculated as 5.16 $mg \cdot L^{-1}$, 1.32 $mg \cdot L^{-1}$, 0.98 $mg \cdot L^{-1}$, 0.77 $mg \cdot L^{-1}$. The mean concentrations of all ions except Mg^{2+} in the initial stage, which includes the first five sequential samples, were higher than those in the last stage because of the wash-out effect on atmospheric particles. The ratios of the mean concentrations of Na^+, Mg^{2+}, Ca^{2+} and K^+ sampled in the initial stage to those in the final stage of the rain event were calculated as 1.77, 0.75, 1.54 and 1.73, respectively. An inverse relationship between the concentration of ions and the rain intensity was observed. The correlations coefficients between the rain intensity and the concentrations of Na^+, Mg^{2+}, Ca^{2+} and K^+ were -0.51, -0.11, -0.48 and -0.29, respectively.

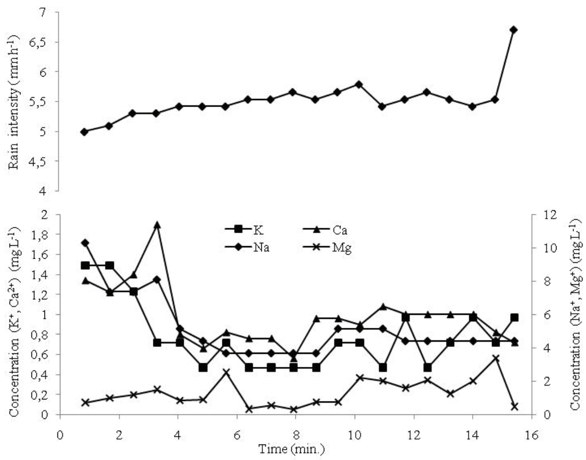

Fig. 6. Variation of the rain intensity and concentration of chemical species during the time of the rain event.

Investigation of sequential samples gives a chance to observe the relationship between the chemical composition of precipitation with the associated meteorological conditions. Sequential collection and analysis can focus on both the precipitation forming processes: rainout and washout. The effect of washout during a precipitation event is expected to be seen during the collection of the early samples, when the concentration of particles in the atmospheric column is highest, and the collision and coalescence process start to remove them. The last phase of a rain event can partly explain the chemical constituents in the rainout process because of the elimination of the wash out to a certain extent (3).

Conclusions

The sequential rain sampling devise which was designed and constructed in this study can be used for investigation of the composition variation during rain events associated with the atmospheric condition, like rain intensity, weather temperature, pressure etc. The sampling devise was applied to only one rain event with the aim of testing it. Investigation of the variation of the chemical components in the rain water and interrelationships between the rain intensity and the concentrations of the chemical components during this rain event were carried out. All of the ions had similar variability with a high correlation during the sampling period. Negative correlations between rain intensity and ion concentrations were found.

With respect to other methods of collecting rain samples sequentially, this sampler's main advantage is its ability to operate unattended. Its advantages with respect to previous samplers of the same type are that: 1) the number of sampling bottles can be increased by adding the valves and changing the algorithm without change in the electronic design of the rain sampler; thus it can collect more samplers; 2) since it does not have moving equipment, it needs less maintenance than its competitors. 3) its is quite low in cost. The sampler's disadvantages are that: 1) it is larger than its competitors, and 2) it is difficult to clean because of its pipes and numerous valves.

Acknowledgements

This work was financially supported by The Scientific Research Center of Marmara University (BAPKO) with project No. FEN-E-040310-0039 and the Scientific and Technological Research Council of Turkey (TUBITAK) with project 109R022.

REFERENCES

1. **Ahmed A.F.M., Singh R.P., Elmubarak A.H.** (1990) Atmos. Environ., **24A**, 2927-2934.
2. **Akkoyunlu B.O., Tayanç M., Karaca M.** (2003) Water Air Soil Poll., **3**, 141-155.
3. **Akkoyunlu B.O., Tayanç M.** (2008) Environ. Int., **34**, 606-612.
4. **Akkoyunlu B.O., Tayanc M., Dogruel, M., Oruc I.** (2008) In: SGEM 2008: 8th International Scientific Conference on Modern Management of Mine Producing, Geology and Environmental Protection, Sofia, Bulgaria, June 16-20, 2008, Vol. 1, 637-643.
5. **Clymo R.S.** (1963) Ann. Bot. N.S., **27**, 309-324.
6. **Cape J.N., van Dijk N., Tang Y.S.** (2009) J. Environ. Monit., **11**, 353-358.
7. **Draxler R.R., Rolph G.D.** (2012) HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model, NOAA Air Resources Laboratory, Silver Spring, MD (http://ready.arl.noaa.gov/HYSPLIT.php).
8. **Dufour C.M.L., Chapman B., Lore A., Nosal M.** (1985) Water Air Soil Poll., **24**, 361-373.
9. **Erisman J.W., Hensen A., Fowler D., Flechard C.R., et al.** (2001) Water Air Soil Poll., **1**, 17-27.
10. **Gatz D.F., Dingle A.N.** (1971) Tellus, **23**, 14-27.
11. **Hansen K., Draaijers G.P., Ivens W.P., Gundersen P., van Leeuwen N.F.** (1994) Atmos. Environ., **28**, 3195-3205.
12. **Krupa S.V.** (2002) Environ. Poll., **120**, 565-594.
13. **Luo W.** (2001) Atmos. Environ., **35**, 2963-2967.
14. **Pryor S.C., Spaulding A.M., Rauwolf H.** (2007) Water Air Soil Poll., **180**, 3-10.
15. **Raynor G.S., McNeil J.P.** (1978) The Brookhaven Automatic Sequential Precipitation Sampler (Report BNL #50818), Brookhaven National Laboratory, Upton, NY.
16. **Robertson J.K., Dolzine T.W., Graham R.C.** (1980) Chemistry of Precipitation from Sequentially Sampled Storms (Publication #EPA 600/4–80–004), USEPA, Research Triangle Park, NC.
17. **Singer A., Shamay Y., Fried M., Ganor E.** (1993) Atmos. Environ., **27A**, 2287-2293.
18. **Vermette S.J., Drake J.J., Landsberger S.** (1988) Water Air Soil Poll., **38**, 37-53.
19. **Yurukova L., Gecheva G.** (2009) Biotechnol. Biotech. Eq., **23**, 955-959.