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DESIGN OF A PLANT-EXPOSURE CUVETTE SYSTEM TO STUDY EFFECTS OF AIR POLLUTANTS

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The construction details of the plant-exposure cuvette system have been described. The cuvettes utilize a dynamic, positive pressure, single-pass flow system which provides uniformity of flow, toxicant mixing and cuvette distribution. Environmental control of exposure inserts or outlets from the cuvettes can be maintained. A brief background is also given together with a proposal of different measurements and studies to be done with this cuvette system.

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Abstract

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The construction details of the plant-exposure cuvette system have been described. The cuvettes utilize a dynamic, positive pressure, single-pass flow system which provides uniformity of flow, toxicant mixing and cuvette distribution. Environmental control of exposure inserts or outlets from the cuvettes can be maintained. A brief background is also given together with a proposal of different measurements and studies to be done with this cuvette system.

Design of a plant-exposure cuvette system to study effects of air pollutants.

Introduction

The impact of air pollution on crops, forest trees and ornamentals as well as natural vegetation has not received as much attention in Sweden as in other industrialised countries.

However, in spite of Sweden's relatively small population and large areas of land, problems caused by air pollution do exist. Today, effects on different ecosystems of acid precipitation and the photochemical oxidant ozone are two environmental problems of great concern.

A widespread method to study air pollution effects on plants is to use different types of exposure cuvettes in the laboratory. Such exposure cuvettes were developed at the Swedish Water and Air Pollution Research Laboratory (IVL), Gothenburg.

In this paper, the design and use of these cuvettes will be described. It also gives a general background as well as suggestions concerning the kinds of measurements for which this type of cuvette might be used.

Background

Air pollutants are chemical compounds, organic or inorganic, which are emitted mainly from automobiles, industries, and combustion plants. These compounds also occur naturally, e.g. heavy metals, nitrogen and sulphur in fossil fuels, but man's activities have led to the formation and accumulation of toxic levels of these compounds. Many organic pollutants are produced synthetically and are not found naturally, e.g. DDT, phenoxy acids, and PCBs.

The impact of air pollutants on vegetation is of international importance, but is accentuated in the industrialised parts of the world, e.g. the USA (1), Japan (2), Great Britain (3), and the Netherlands (4). Lists of relative susceptibility of plant species to different air pollutants including ozone, SO_2, HF, PAN, NO_2 and heavy metals have been published (5, 6). In these studies, susceptibility of the plants is primarily related to foliar responses. Furthermore, most studies deal with short-term, high-level exposures of plants, i.e. acute doses. In nature, plants are often subject to long-term, low-level exposures of gases, i.e. chronic doses, and more information regarding the impact of such exposures is vitally needed. It is likely that responses at chronic levels would be different (7, 8). Reduced yield and growth (9, 10), changed metabolic content of plants (11, 12), and altered community composition by natural selection of resistant species (13) are some of the possible effects.

In the ecosystem plants are exposed to several pollutants in a variety of combinations under continuously varying environmental conditions, leading to an extremely complex interaction between air pollutants and plants (14, 15).

Plants are also stressed by many biotic factors, such as insects, viruses and fungi. There are also some reports that illustrate negative effects of air pollutants on plant tolerance to these biotic stresses (16).

Regardless of the level of air pollutant, it is clear when studying effects of air pollutants on vegetation that biochemistry, physiology, ecology and economy are interrelated. A scheme suggesting the relationship between these disciplines is shown in Figure 1.

Measurements for which the exposure cuvettes are useful

Many different aspects must be considered in the study of air pollution effects on vegetation (Figure 1). For controlled studies on the impact of air pollutants on plants, exposure cuvettes in the laboratory are essential. Several factors which affect the plant's response to air pollutants have been identified. Some of the more important factors are concentration of the pollutant during exposure, length of exposure time, the duration and intensity of environmental factors during exposure and the plant's phenological condition, genetic make-up, and cultural history. Consequently, in order to compare work from other laboratories and to be able to duplicate work of various investigators, it is essential that these factors can be controlled and decribed during exposure studies.

Three study areas which could utilise such exposure cuvettes are presented below:

1. The screening of species or varieties for air pollutant susceptibility. Foliar responses (necrosis, chlorosis) could then be studied as well as photosynthesis, respiration and transpiration. Seedlings of Swedish crops and forest trees could be exposed to a variety of air pollutants, singly or in combination. Such screenings would give an indication of what crops and trees are air pollution susceptible or tolerant. This knowledge would also be useful in the future if we face a situation where air pollution resistant crops become a necessity in Sweden.

2. The study of deposition of pollutants on plant surfaces, uptake of air pollutants by plants and subsequent chemical transformation of the compounds, and other processes related to the ultimate fate of the pollutant.

3. The study of effects of chronic exposure. In the field, long-term low levels of air pollutants may reduce growth, yield and reproductive capacity, which is not clearly visible to the eye. As a consequence, it may alter the community composition of plants in natural ecosystems. It is very difficult to successfully correlate changes in biomass as well as disappearance of susceptible species in the field with just slightly elevated air pollutant levels. If reduced productivity, i.e. reduced flowering and fruiting capacity, or an extreme sensitivity of crops and wild plants could be demonstrated in the cuvettes after a long-term low-level exposure, such data might be used in the development of prediction models of potential field effects of chronic exposure.

Design and construction details

IVL today has three exposure cuvettes designed as shown in detail in Figure 2.

In Figure 3 the whole exposure system is described. The system is under a positive pressure and it provides a uniform flow throught the cuvettes.

Exposure cuvettes

The three cuvettes are made of glass, which is practically inert. The volume of each cuvette is five litres and it has two openings for air inlet and outlet. To provide mixture of the air in the cuvettes a special round made of teflon manifold was constructed (Figure 2). The plant or plants to be exposed are placed in a nutrient solution which is kept in a glass pot of 700 ml. The pot has three openings, two for nutrient solution (inlet and outlet) and one for areation. The pot with the plant in it is placed under the chamber. A thin teflon flat, with a hole for the stem, is placed on top of the pot to prevent the nutrient solution from evaporating or reacting with the air in the cuvette. The nutrient pot is black to prevent algae from growing. The chamber and nutrient pot are held together with a metal clamp.

Air and test gas generating system

The air and test gas generating system for the cuvettes is detailed in Figure 3. All lines and joints are made of glass, teflon or plyethylene. Ambient air from outside is pumped into the system with a pump through two filter columns of silicagel which absorbe most of the water in the air (A). The incoming air passes through a cleaning plenum equipped with an initial particle filter (B_1), a charcoal filter to eliminate organic compounds (B_2), a filter with $KMnO_4$(B_3) and K_2CO_3(B_4) to eliminate NO_x and

SO_2 and other acid gases, a filter with oxalic acid to eliminate NH_3 (B_5) and another particle filter (B_6). Parts of the clean air passes through a needle valve into a humidifying unit (C) to reach the humidity chosen for a certain experiment. This unit consists of a peristaltic pump, which introduces water with a constant flow into a heated flask where the water is evaporated and mixed with the dry air.

After the dry and wet air has been mixed together in the mixing chamber (D) the system divides in two lines. One line - the control (reference) - goes directly to one cuvette (E). The trace gases (pollutants) are added to the other line through a needle valve and a capillar from a gas bottle or a permeation tube (F). Present construction limits the number of pollutants that can be added to one but the design can be changed to allow more pollutants to be added and mixed before entering the cuvettes (E_2 and E_3). After the addition of the pollutants the air passes through another mixing chamber (G). Then the line is divided before entering the two exposure cuvettes (E_2 and E_3). The flow through each cuvette is controlled by needle valves and normally set to 5 litres per minute.

Analyses of trace gases

Analyses of trace gases is carried out before or/and after the air has passed through the cuvettes (Fig. 3; H_1, H_2, H_3, I_1, I_2, I_3). SO_2 and NO_x are analysed with a FPD monitor (Meloy SA 160) and a chemiluminescent nitrogen oxides analyzer (Monitor Labs 8440) respectively.

Analyses of CO_2

A CO_2 instrument (Infrared photometer) (UNOR 2) is connected to the cuvettes. It records the difference in CO_2-concentrations between the ambient air and either the control cuvette or the cuvettes with an air pollutant. In this way a direct measurement of the photosynthesis activity is recieved.

Environmental control

Plants are illuminated with an Osram Dysprosium lamp (400 W). This lamp has a spectral energy distribution which rather well simulates natural day light. The humidity and temperature is monitored by a hydrothermograph. At present, the temperature in the cuvettes cannot be regulated and the temperature inside the cuvettes is about $0,5^{o}C$ higher than the room temperature.

Further development of the system will continuosly be done.

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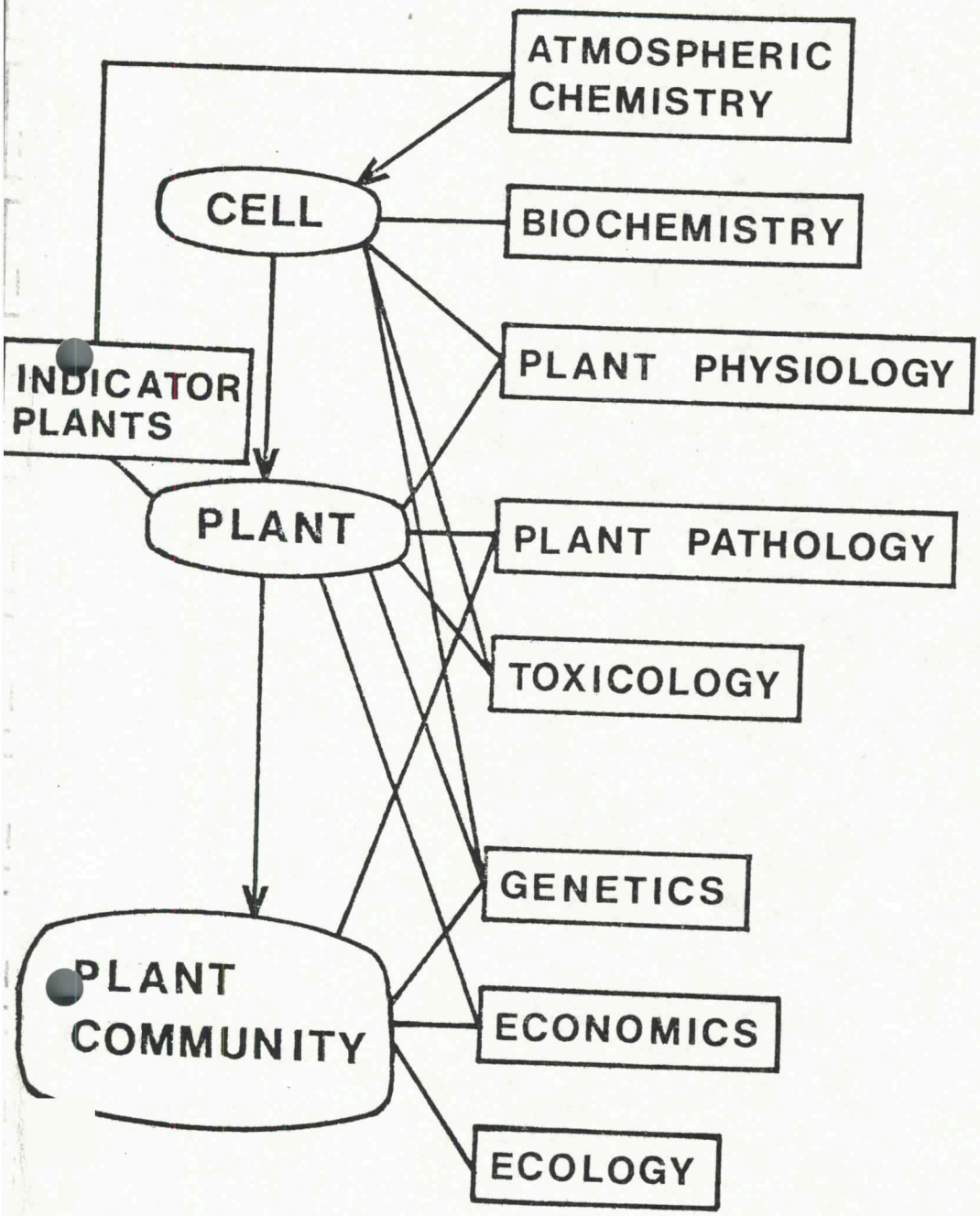
Figure 1

AIR POLLUTION EFFECTS ON VEGETATION



Examples of effect studies:

Metabolic changes and alterations, e.g. enzyme inhibitions, lipid destructions, pigment destruction, e.g. chlorofyll degradation, hormone disturbances

Photosynthesis changes
Transpiration
Respiration
Cellmembrane destruction
increase or decrease of plant growth

Viruses, Fungi, Bacteria } increase or decrease in number

Accumulation of foreign compounds, like heavy metals fluorides, DDT, etc. or accumulation of compounds that are natural plant constituents such as sulphur and nitrogen

DNA and RNA changes
Selection of susceptible and tolerant plants

Quality, quantity

Population dynamics

Community changes

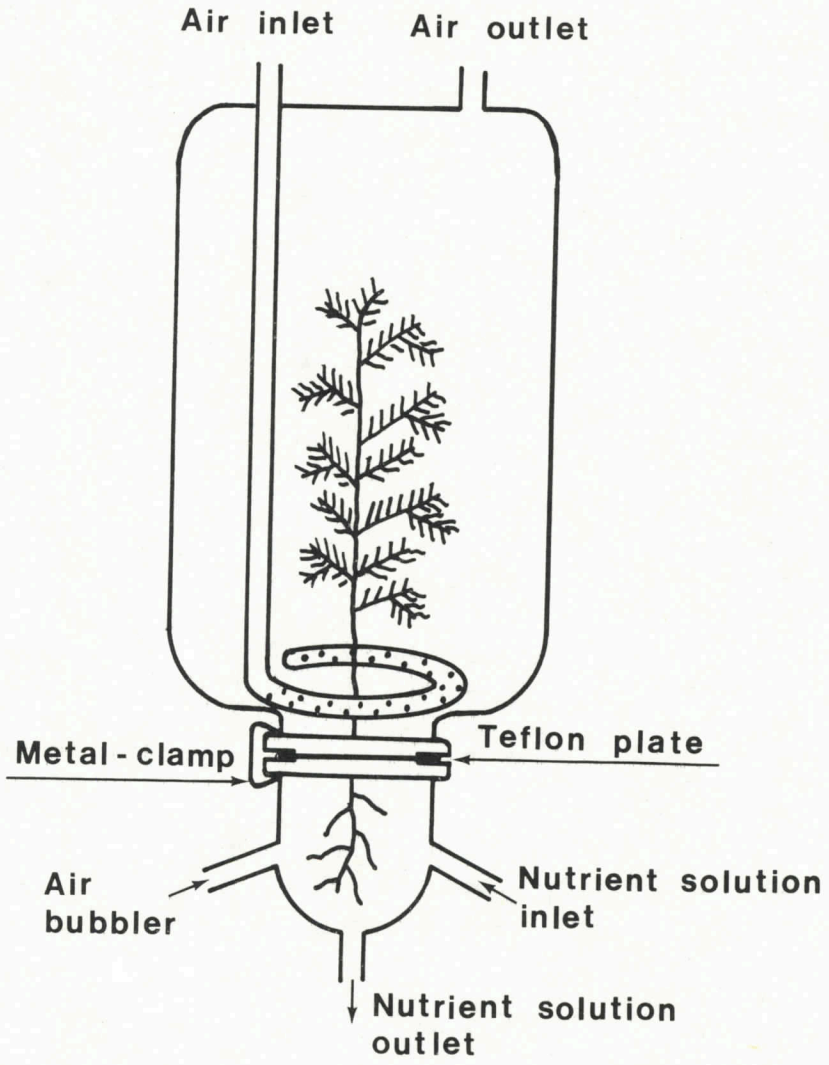


Figure 2 Exposure cuvette

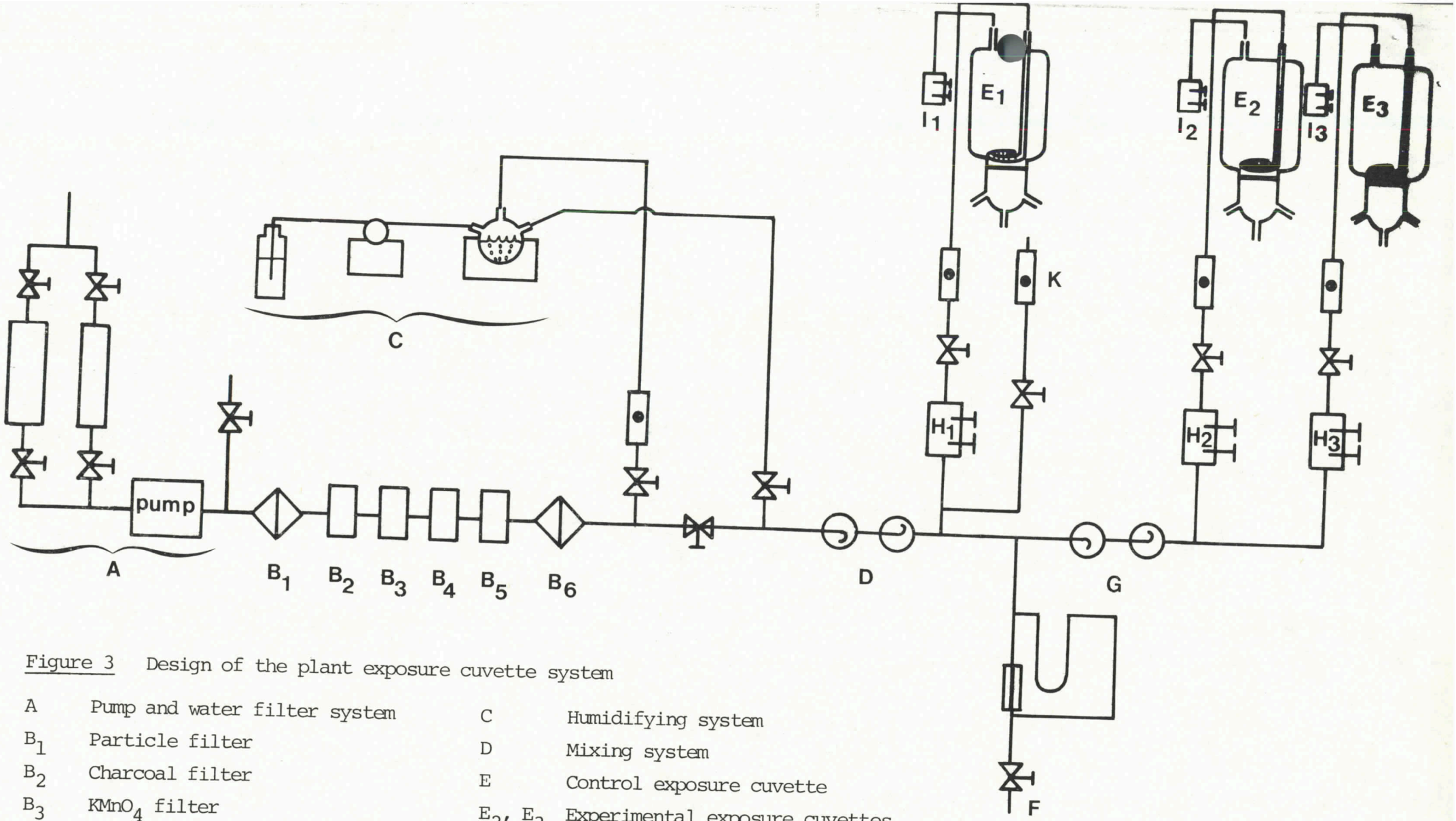


Figure 3 Design of the plant exposure cuvette system

A	Pump and water filter system
B_1	Particle filter
B_2	Charcoal filter
B_3	$KMnO_4$ filter
B_4	K_2CO_3 filter
B_5	Oxalic acid filter
B_6	Particle filter
C	Humidifying system
D	Mixing system
E	Control exposure cuvette
E_2, E_3	Experimental exposure cuvettes
F	Pollutants addition with capillar and manometer
G	Mixing system
H_1,H_2,H_3	Gas analyses before cuvette
I_1,I_2,I_3	Gas analyses after cuvette
K	Extra gas line with filtered air