

Jordan Journal of Physics

ARTICLE

Measurements of Black Carbon Levels Using Photoacoustic Technique inside Different Buildings at Yarmouk University/Jordan

K. Hamasha^a

^a *Department of Physics, Yarmouk University, Irbid, Jordan.*

Received on: 9/6/2008; Accepted on: 9/10/2008

Abstract: Measurements of the black carbon light absorption coefficients (B_{abs}) inside different buildings at Yarmouk University were done using the Photoacoustic instrument at wavelength of 870nm. The main source of black carbon particles inside buildings are smoking and the nearby traffics. The average values of B_{abs} for the buildings that prohibited smoking in were less than that for the buildings that allowed smoking in. The highest average value of B_{abs} was found inside the science building, it was equal to 7.97 Mm^{-1} . This building is close to a main street, and smoking in is allowed. Calculation of the black carbon mass concentration (BC) were done based on the measured B_{abs} and the light absorption efficiency for black carbon α_a . BC found to have average value equal to $0.725 \mu\text{g}/\text{m}^3$ for the prohibited smoking buildings and $1.045 \mu\text{g}/\text{m}^3$ for the allowed smoking buildings. The building that is nearby traffic had the largest value of BC $1.30 \mu\text{g}/\text{m}^3$.

Keywords: Absorption coefficient; Black carbon; Absorption efficiency; Indoor pollution.

Introduction

Air is the ocean we breathe. Air supplies us with oxygen which is essential for our bodies to live. Air is 99.9% nitrogen, oxygen, water vapor and inert gases. Human activities can release substances into the air, some of which can cause problems for humans, plants, and animals. There are several main types of pollution and well-known effects of pollution which are commonly discussed. These include smog, acid rain, the greenhouse effect, and "holes" in the ozone layer. Each of these problems has serious implications for our health and well-being as well as for the whole environment.

One type of air pollution is the release of particles (aerosols) into the air from burning fuel for energy. Aerosols are defined as the relatively stable suspensions of solid or liquid particles in gas. There are many properties of particles that are important for

their role in the atmospheric processes. These include number concentration, mass, size, chemical composition, and aerodynamic and chemical properties [1, 2]. Of these, size is very important. It is related to the source of particles and their impact on health [3-5], visibility, and climate [6].

Light absorbing carbon particles (organic carbon and black carbon) are the most abundant and efficient light absorbing component in the atmosphere in the visible spectrum. It typically depends inversely on wavelength [7, 8]. Organic carbon is strongly wavelength dependent, with increased absorption for UV and short wavelength visible radiation, but hardly at all at 870 nm. Black carbon is very likely to dominate at 870 nm [9]. When aerosols absorb light, the energy of the light is transferred to the particles as heat and eventually is given to the surrounding gas.

Aerosol particles in the atmosphere have a great influence on fluxes of solar energy and the accompanied fluctuations in temperature caused by changes in the aerosol [7].

Black carbon, the main constituent of soot, is almost exclusively responsible for aerosol light absorption at long wavelength visible radiation and near infrared wavelengths. This type of pollution is sometimes referred to as black carbon pollution. The exhaust from burning fuels in automobiles, homes, and industries is a major source of pollution in the air. Even the burning of wood and charcoal in fireplaces and barbeques can release significant quantities of soot into the air. Some of these pollutants can be created by indoor activities such as smoking and cooking. So pollution also needs to be considered inside homes, offices, and schools. According to the world health report 2002 indoor air pollution is responsible for 2.7% of the global burden of disease [10]. We spend about 80-90% of our time inside buildings, and so our exposure to harmful indoor pollutants can be serious [3-5]. It is therefore important to consider both indoor and outdoor air pollution.

This study is aimed to measure the indoor black carbon levels at different buildings of Yarmouk University/Jordan. Photoacoustic technique will be used to measure the black carbon light absorption coefficients at wavelength of 870 nm. The black carbon mass concentrations will be calculated based on B_{abs} .

Experimental Procedure

Measurement of aerosol light absorption coefficients is so important because of its relation to atmospheric pollution as it affects health, visibility, and climate. One of the ways to do these measurements is by using the Desert Research Institute (DRI) photoacoustic instrument [11-13]. Fig. 1 shows a schematic view of the photoacoustic spectrometer. The principle of operation is as follows, the laser beam power is modulated at the acoustic resonance frequency of the photoacoustic spectrometer. The aerosols absorb the laser's light energy and convert into a thermal energy or heat. This heat flows quickly to the surrounding air by conduction (aerosol is small and have

high thermal conductivity). Heated air responds by expanding its pressure. With the acoustic resonator, the pressure disturbance or acoustic signal, can be amplified and detected by a microphone. The sound pressure associated with aerosol light absorption, can be obtained as a measure of black carbon. This technique creates a way to measure the light absorption of the aerosols, and the instrument in its current form is unique.

In this work a measurement of the black carbon light absorption coefficients inside five different buildings at Yarmouk University were done. These buildings were; Science building, Education building, Shari'a building, Library building, and English village building.

Photoacoustic spectrometer instrument with 870 nm wavelength was used in this study to calculate the black carbon light absorption coefficients indoor. The experimental procedure in a simple way is to install the setup of the instrument and then collect data. The instrument is controlled by a Labview program. Before installation, the instrument should be located in well-ventilated area where the air could be brought in. When it is ready to sample air, the instrument inlet flexible tubing is connected to the inlet of a copper tubing so that an air sample can be pulled in. This copper tubing was fixed to some stable wall or ceiling with its inlet open all the time during sampling. The height of the inlet tube is about 2 meters.

The measured data using the Photoacoustic instrument were the black carbon light absorption coefficients (B_{abs}) versus time. Then the black carbon mass concentrations (BC) were calculated from B_{abs} using the light absorption efficiency for black carbon α_a [11, 14, 15].

where:

$$B_{abs} = BC \times \alpha_a \quad (1)$$

where B_{abs} in $Mm^{-1}(10^{-6}m^{-1})$, BC in $\mu g/m^3$, and α_a in m^2/g .

$$\alpha_a = 10m^2/g \text{ for } \lambda = 532nm \quad [13] \quad (2)$$

Since B_{abs} is proportional to λ^{-1} [16]; then α_a is proportional to λ^{-1}

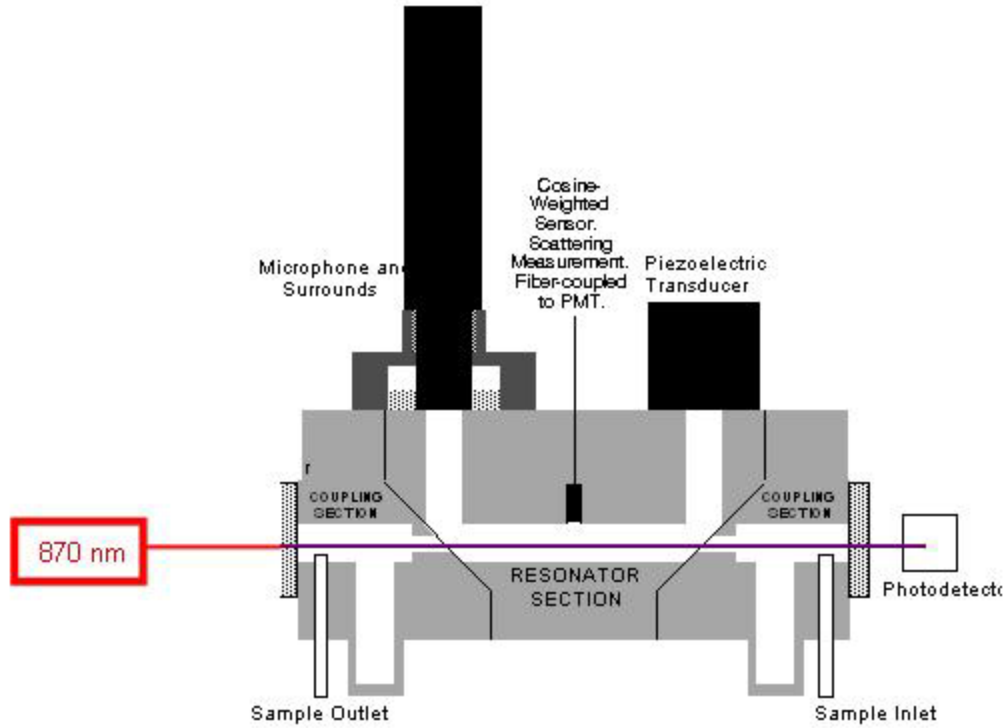


FIG.1. A schematic view of the photoacoustic spectrometer instrument. (PMT is a photomultiplier)

So:

$$\left. \begin{aligned} \frac{\alpha_a(870\text{nm})}{\alpha_a(532\text{nm})} &= \left(\frac{870}{532}\right)^{-1} \\ \Rightarrow \alpha_a(870\text{nm}) &= \alpha_a(532\text{nm}) \left(\frac{870}{532}\right)^{-1} \\ &= 10 \times 0.611 \\ &= 6.11 \text{ m}^2/\text{g} \end{aligned} \right\} \quad (3)$$

From equation (1)

$$\text{BC}(870\text{nm}) = B_{\text{abs}}(870\text{nm}) / 6.11 \quad (4)$$

Results and Discussion

Measurements of the black carbon light absorption coefficients (B_{abs}) using the photoacoustic instrument were done inside different buildings at Yarmouk University/Jordan on summer 2007. These measurements were done inside the first floor of the five buildings. All measurements were done in the halls outside the classrooms; these places were crowded with students. Students usually relax at these places between classes eating, talking, listening to music, and smoking. The source of black carbon inside buildings was the human activities and the incoming aerosol from outside that travel with air. Inside these

buildings there were no kitchens, so no cooking source of black carbon. As the time of the measurements was summer, there was no source black carbon from heating systems. The sampling was done during summer semester; the classes schedule is the same for the five business days (Sunday through Thursday).

Measurements of black carbon light absorption coefficients (B_{abs}) using the photoacoustic instrument at first floor of the science building were held on Wednesday June 27th 2007 between 9:30AM to 4:30 PM. Fig. 2 shows a time series plot of the measured B_{abs} and the calculated BC using eq. 4. Photoacoustic B_{abs} measurements were done for the other four buildings at the same period of time on: Thursday June 28th 2007 for the Education building, Monday July 2nd 2007 for the Shari'a building, Wednesday July 4th 2007 for the English Village building, and Thursday July 5th 2007 for the Library building. The average temperatures in these five targeted days were between 29 and 32°C.

Figs 3-6 plot the measured B_{abs} and the calculated BC in the halls of the first floor of the specified buildings. Fig. 7 shows a chart of the BC for the targeted five buildings.

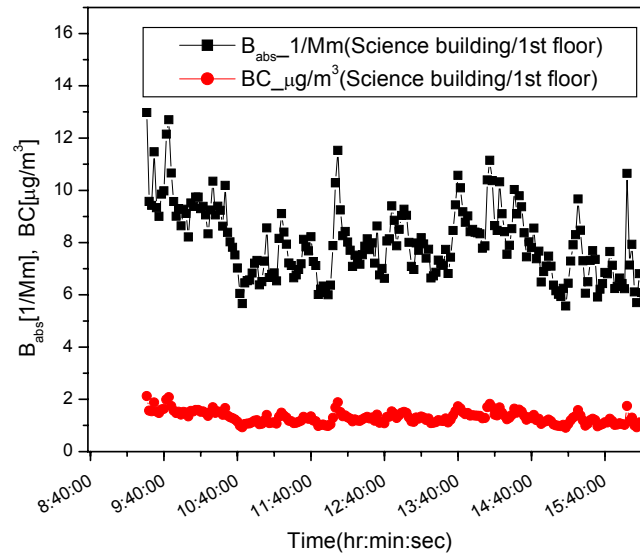


FIG.2. Time series of the measured B_{abs} and the calculated BC at the wavelength of 870 nm in the first floor of the Science building.

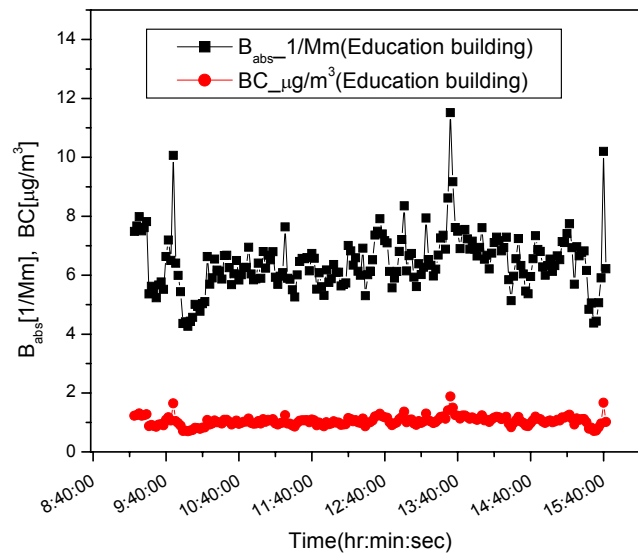


FIG.3. Time series of the measured B_{abs} and the calculated BC at the wavelength of 870 nm in the first floor of the Education building.

From these figures the levels of black carbon were different from one building to another. As a result of the comparison between the black carbon levels for these buildings; the Science building had the highest level, about $7.97 \text{ Mm}^{-1} B_{abs}$ and $1.30 \mu\text{g}/\text{m}^3 \text{ BC}$. The Library and Shari'a buildings had the lowest level, about $4.39 \text{ Mm}^{-1} B_{abs}$ and $0.72 \mu\text{g}/\text{m}^3 \text{ BC}$ for the library building,

and about $4.47 \text{ Mm}^{-1} B_{abs}$ and $0.73 \mu\text{g}/\text{m}^3 \text{ BC}$ for the Shari'a building. The other two buildings, Education and English village had close levels about $6.42 \text{ Mm}^{-1} B_{abs}$ and $1.05 \mu\text{g}/\text{m}^3 \text{ BC}$ for the Education and about $6.37 \text{ Mm}^{-1} B_{abs}$ and $1.04 \mu\text{g}/\text{m}^3 \text{ BC}$ for the English Village building. These results were summarized in Table 1.

TABLE 1. Black carbon levels at the Yarmouk University buildings.

Building	Average B_{abs} [1/Mm]	Max B_{abs} [1/Mm]	Min B_{abs} [1/Mm]	Average BC [$\mu\text{g}/\text{m}^3$]
Science/1 st floor	7.97 ± 0.098	12.98	5.47	1.30 ± 0.016
Shari'a/1 st floor	4.47 ± 0.075	11.23	2.34	0.73 ± 0.012
Education/1 st floor	6.42 ± 0.071	11.51	4.27	1.05 ± 0.011
English Village/1 st floor	6.37 ± 0.144	19.48	3.45	1.04 ± 0.023
Library/1 st floor	4.39 ± 0.050	6.24	2.94	0.72 ± 0.008

Indoor black carbon pollutant is very important even for a very small amount because we spend most of our time inside buildings, and so our exposure to harmful indoor pollutants can be serious, since these particles could be easily inhaled with the breathing air to the lower respiratory system. Because black carbon aerosols are fine and hyperfine particles (diameter is submicron levels $\sim (\mu\text{m} - \text{nm})$) and fall in the respirable size range. These particles can reach the alveolar region where gas exchange occurs. This region is not coated with a protective mucus layer, and here the clearance time for deposited particles is much greater than in the upper respiratory track; hence the potential for health effects is much greater [17].

From this study at Yarmouk University, the two buildings that show low levels of black carbon aerosols are the buildings that prohibited smoking inside. The other buildings that had higher levels of black

carbon aerosols are the buildings that allow smoking inside. As a result of this study the author recommends that smoking will be prohibited inside all the buildings at Yarmouk University because of its bad health effect on all people who breathe these harmful aerosols [18], whether they are smokers or nonsmokers.

The Science building shows the highest level because it is the closest building to very crowded main street. Crowded main street means a lot of automobiles and a lot of aerosol particles that could easily travel by air to the nearest building through the opened doors and windows.

This study was done on summer season. We expect that if this study is repeated in winter the indoor BC levels will be greater than these values because of the heating activities with doors and windows usually closed. Therefore, aerosol particles will stay in.

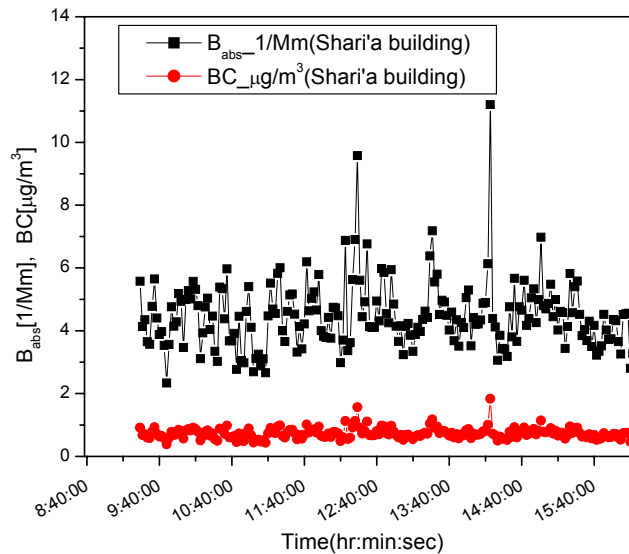


FIG.4. Time series of the measured B_{abs} and the calculated BC at the wavelength of 870 nm in the first floor of the Shari'a building.

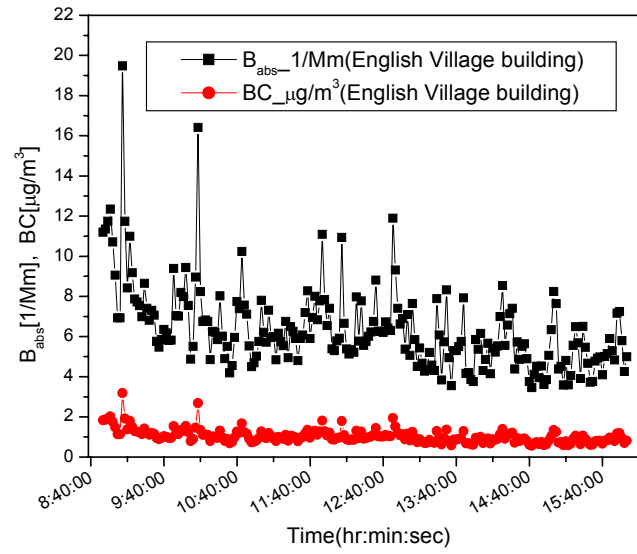


FIG.5. Time series of the measured B_{abs} and the calculated BC at the wavelength of 870 nm in the first floor of the English Village building.

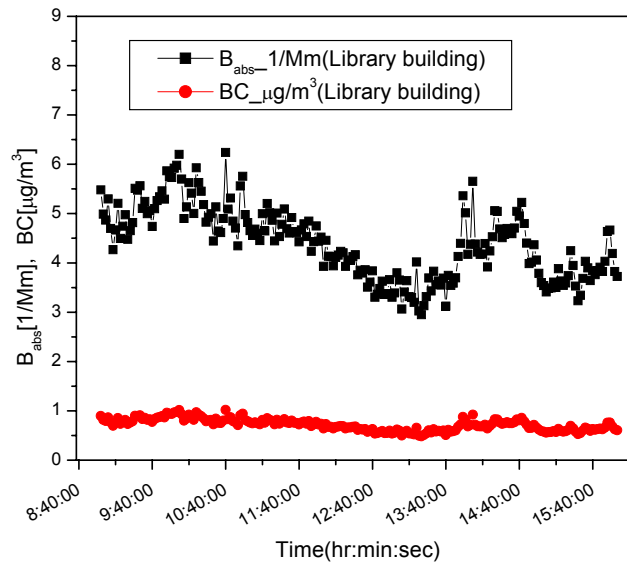


FIG.6. Time series of the measured B_{abs} and the calculated BC at the wavelength of 870 nm in the first floor of the Library building.

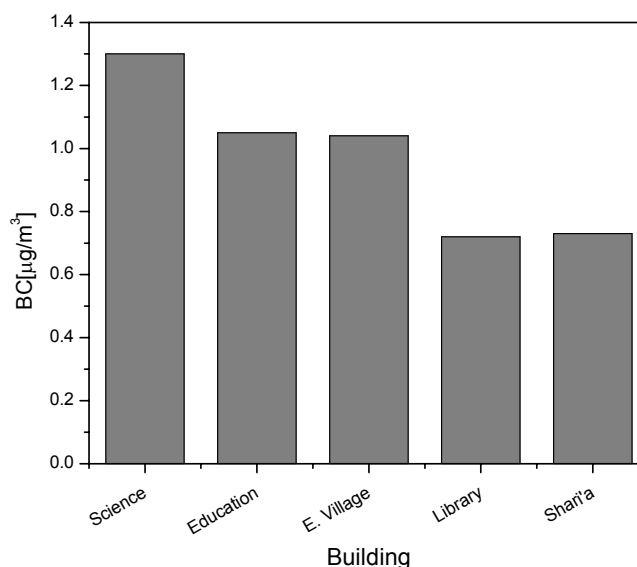


FIG.7. Chart of the black carbon mass concentration levels in the halls of the first floor of the; Science building, Education building, English village building, Library building, and Shari'a building, at Yarmouk University/Jordan.

Conclusions

This study conducted at Yarmouk University shows that; the black carbon levels are the highest inside the building that is close to a main crowded street. There were two categories of buildings with respect to their black carbon levels inside. The first one shows low levels of black carbon aerosols inside, and the second one shows higher levels of black carbon inside. These two categories are the prohibited smoking buildings and the allowed smoking building respectively.

As a result of this study we recommend to prohibit smoking inside all the buildings of Yarmouk University because of its negative health impact for people who breathe these harmful aerosols whether they are smokers or nonsmokers [18].

Acknowledgments

Photoacoustic instrument was borrowed from the United State of America via agreement between Yarmouk University Deanship of Research and Graduate Studies and Dr. Patrick Arnott from the Physics Department at the University of Nevada/Reno.

The author acknowledges the financial support by grant number 2006/25 from the Deanship of Scientific Research and Graduate Studies at Yarmouk University.

It is a pleasure to thank Dr. Patrick Arnott for his helpful discussion, and Hussam Al-Omari, and Mohammad Jaradat for their help in the field measurements.

References

- [1] Chang, S.G., Brodzinsky, R., Gundle, L.A. and Novakov, T., "Chemical and Catalytic Properties of elemental carbon", In *Particulate Carbon: Atmospheric Life Cycle* G.T. Wolff and R.L. Klimsch, Eds. (Plenum, New York, 1982), p159.
- [2] Walker, P.L., "Chemistry and physics of carbon". vol. 2, (Marcel Dekker Inc., NewYork, USA, 1966).
- [3] Harber, P., Muranko, H., Solis, S., Torossian, A. and Merz, B., *J. Occup. Environ. Med.*, 45 (2003) 144.
- [4] Puntoni, R., Ceppi, M., Gennaro, V., Ugolini, D., Puntoni, M., La Manna, G., Casella, C. and Merlo, D., *Cancer Causes Control*, 15 (2004) 511.
- [5] Borm, P.J., Schins, R.P. and Alberecht, C., *Int. J. Cancer*, 110 (2004) 3.
- [6] Finlayson-Pitts, B.J., James J. and Pitts, N. *Chemistry of the Upper and Lower Atmosphere*, Academic press.
- [7] Horvath, H. (1993). *Atmospheric Environment*, 27A (2000) 293.
- [8] Horvath, H., *Atmospheric Environment*, 13 (1997) 2885.
- [9] Lewis, K., Arnott, W.P., Moosmüller, H. and Wold, E., *J. Geophysical research*, 113 (2008) D16203. doi: 10.10292007JD009699.
- [10] Indoor air pollution, <http://www.who.int/indoorair/en/>, URL, July 8th 2008.
- [11] Arnott, W.P., Moosmüller, H., Rogers, C.F., Jin, T. and Bruch, R., *Atmospheric Environment*, 33 (1999) 2845.
- [12] Arnott, W.P., Moosmüller, H. and Walker, J., *Review of Scientific Instruments*, 71 (2000) 4545.
- [13] Arnott, W.P., Moosmüller, H., Sheridan, P.J., Orgen, J.A., Raspet, R., Slaton, W.V., Hand, J.L., Kreidenwies, S.M. and Collett, J.L., *J. Geophys. Res.*, D1 (2003) 4034.
- [14] Fuller, A., Malm, W. and Kreidenweis S., *J. Geophys. Res.*, 104 (1999) 15941.
- [15] Moosmuller, H., Arnott, W.P., Rogers, C.F., Chow, J.C. and Frazier, C.A., *J. Geophys. Res.*, 103 (1998) 28149.
- [16] Kirchstetter, T.W., Novakov, T. and Hobbs, P.V., *J. Geophys. Res.* 109 (2004) 1208. doi:10.1029/2004JD004999
- [17] Phalen, R.F., "Inhalation Studies: Foundation and Techniques", (CRC Press, Boca Raton, FL, 1984).
- [18] Jason, K.L.T., Larson, V., Koenig, J.Q., Mar, T.F., Fields, C., Stewart, J. and Lippmann, M., *Environ Health Perspec*, 113 (2005)1741.