

Health impacts in South-central Chile due to misuse of wood-burning stoves

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Introduction

After the episode that occurred in London in December of 1952 in which more than four thousand people died as a result of acute exposure to atmospheric contaminants (particulate matter and sulfur dioxide, principally), there are no doubts that air quality has an important effect on the health of the population. Exposure to air and the intake of air and its components are permanent and obligatory. “We can choose the water we drink and the food that we eat, but we cannot choose the air that we breathe.” Given that a person inhales between 13 and 15 m³ (between 13,000 or 15,000 liters), it is understood that humans are highly vulnerable to atmospheric pollution.

As is shown in Fig. 1, in many cities in the central and southern parts of Chile, (Rancagua, Talca, Chillán, Gran Concepción, Los Angeles, Temuco, Osorno, Valdivia and Coyhaique) the problem of atmospheric pollution from particulate matter (PM) exists [Ministerio del Medio Ambiente, 2011]. This agent is principally emitted by wood stoves and ovens that use firewood, due to the bad practices or misuse of these devices, such as the burning of wet wood (hu-

midity over 25%) in articles of precarious technology, that are additionally operated in an undesirable manner (closure of air intakes). Also, the consumption of firewood is excessive, due to the poor quality or lack of thermal insulation in homes.

In these same cities, during the winter period, it is frequent that health centers are collapsed by the grand number of visits associated with respiratory and cardiovascular illnesses in children and the elderly, primarily. However, it is important to ask, “Are all respiratory illnesses caused by atmospheric pollution?” As well as, “What percentage is attributable to poor air quality?” If the concentrations of PM decrease as a consequence of a Decontamination Plan, will there be less occurrence of respiratory diseases? This study has the principle objective of answering these questions, as well as the explanation of PMs and their health risks for humans.

Theoretical framework

Description of the Particulate Matter (PM)

PM is the name given to all solid and liquid particles

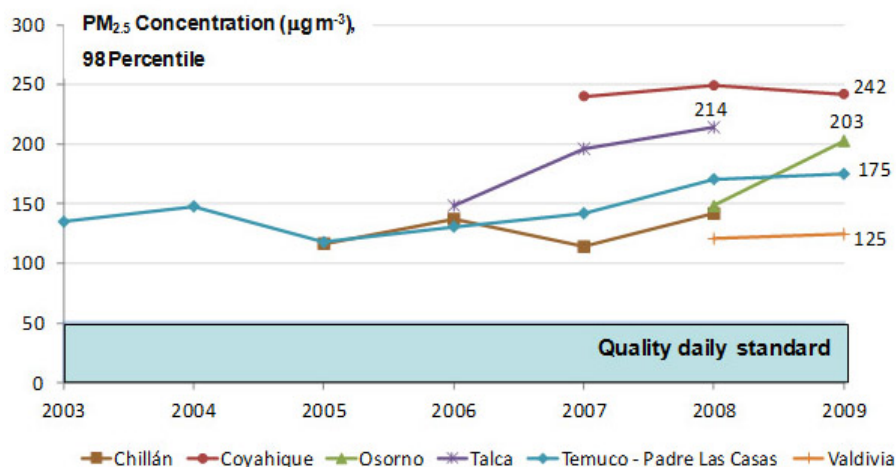


Figure 1 98 Percentile of the concentrations (24 h average) of PM_{2.5} registered annually in different cities in the south of Chile [Ministerio del Medio Ambiente, 2011].

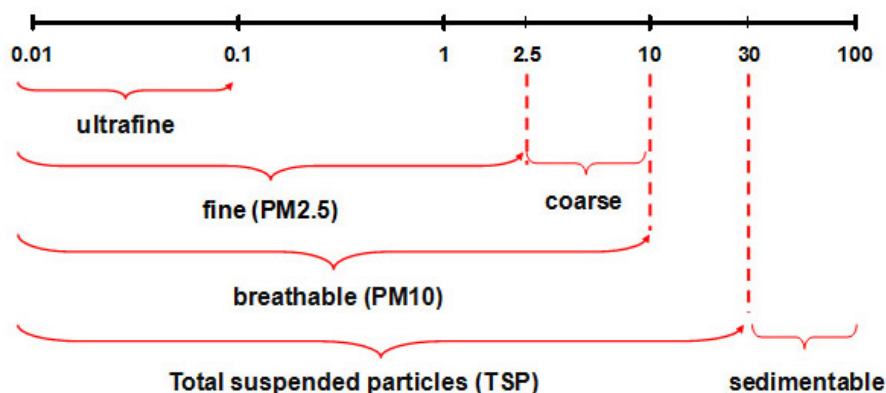


Figure 2 Size Classification of PM according to size (Author's elaboration).

suspended in the air, having different size and varied composition. PM is classified according to its size (Fig. 2).

Total suspended particles (TSP): These are particles whose diameter is equal to or less than 30 mm (micrometers). In a stable atmosphere (high pressure, low temperatures and the absence of wind), these particles accumulate, remaining suspended at few meters of altitude. Only by rain action are these particles brought to the surface.

Breathable Particulate Material (PM10): corresponds to the conjunction of particles whose aerodynamic diameter is equal to or less than 10 mm. Given their size, these particles are inhalable, which means that they can enter into the respiratory system.

Fine particulate material (PM_{2.5}): corresponds to the conjunction of particles whose aerodynamic diameter is equal to or less than 2.5 mm. The interest in studying specifically these particles is in that they have a higher potential human health risk, given that they are smaller and they can travel deeper into the respiratory system. Particles that have a diameter equal to or less than 1 mm can arrive to the alveolus, where they are deposited into the bloodstream, being distributed to the entire organism.

It is shown in literature that a high percentage of ultrafine particles (diameter less than 0.1 mm), are not exhaled, being retained in the human organism, especially, smaller particles [Daigle et al., 2003].

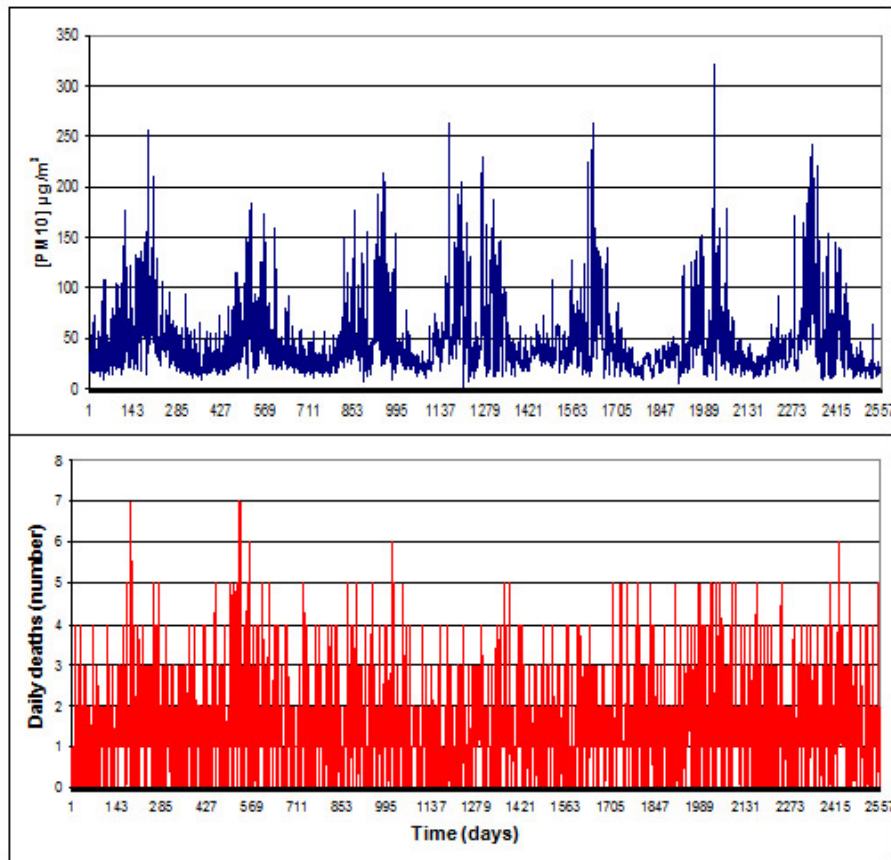


Figure 3 Time series (1998-2005) for: (a) PM10 and (b) mortality for respiratory causes [Sanhueza et al. 2009].

Effects of PM on Human Health

The previous explanation allows the understanding that the inhalation of PM affects not only the respiratory system, but also the cardiovascular system. In effect, it is plausible to associate alterations in cardiac functions and in the rheology of the blood to the exposure of this contaminant. The brain-vascular ischemia or arteriosclerosis can be provoked by the presence of PM in the circulatory system [Pope and Dockery, 2006].

The effects of PM on human health can be seen in different time scales: in the short term acute effects are observed, produced by a punctual exposure to elevated concentrations of the pollutant; and in the long term, chronic illnesses are observed because of the continuous exposure to PM, even when the concentration levels are considered innocuous [Donaldson et al., 2001].

The damage that is provoked by bad air quality on human health has a high cost for society. Lost work and school days, premature deaths, hospitalizations and emergency room visits are common results [CARB, 2006].

Epidemiological Time-Series Studies

The most frequent epidemiological studies are centered in the short term analysis [Saez et al., 1999]. These studies aim to quantitatively correlate the daily exposure to PM with the number of daily mortality and morbidity events for respiratory and cardiovascular illnesses. The result of this correlation is the *Relative Risk*, a parameter that takes into account the increase in the probability of getting sick or dying when the concentration of PM is increased, for example in 100 mg m^{-3} .

These studies use time series (daily data from a

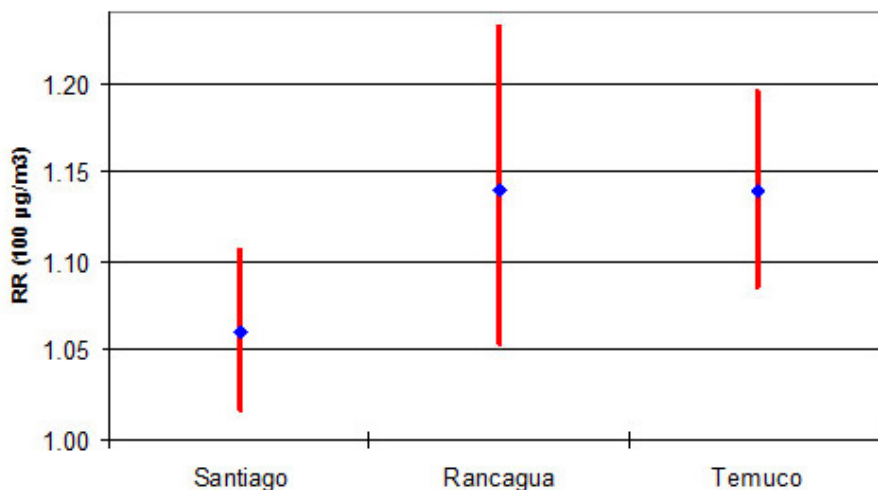


Figure 4 Relative risks of respiratory illnesses in different cities of south-central Chile, for an increase in PM10 in 100 [mg m⁻³] [Sanhueza et al. 2009].

period of at least 3 years), for the variable to be explained (health events) as well as for the variables identified as a cause (Fig. 3). In this point, it is important to note that the exposure to PM is absolutely not the exclusive cause of all respiratory and cardiovascular illness. Meteorological conditions such as low temperatures and elevated relative humidity are a basal source. On the other hand, epidemics are common due to influenza and other virus. Thus given, the challenge for the investigator is to isolate the effects attributable to PM [Ballester et al., 1999].

Results

Relative risks in the city of Temuco and Padre Las Casas

In a study recently carried out in the city of Temuco-Padre Las Casas [Sanhueza et al., 2009], in which the authors of the current study participated and in which an internationally validated protocol was applied, it was determined that upon the increase of the concentration of PM10 in 100 mg m⁻³, 12% of the total mortality by respiratory causes was attributable to this contaminant. For the age group of 65 years and older, the percentage increased to 14%. Similar results were obtained for death by cardiovascular causes.

For morbidity results, again the age group most susceptible was the group of 65+ years. Of the total cases of respiratory illnesses observed in this group, 11% was attributable to the exposure to PM when the concentrations of this contaminant had increased in 100 mg m⁻³. This percentage reached 6.5% for cardiac illnesses.

When the results of this study were compared with those that were obtained in Santiago (Fig. 4), it was observed that for the same increase in the PM concentration, the relative risk for the population of Temuco was greater. Among the hypothesis that could explain this difference is that: PM10 in Temuco contains a higher percentage of PM2.5, and PM10 in Temuco contains a higher level of toxic organic compounds.

The high relative risks obtained in Temuco are consistent with toxicology studies (in cell cultures) that have demonstrated that PM generated by residential combustion of firewood has toxicity ten times higher than the PM produced by diesel combustion [Klippel and Nussbaumer, 2007].

Composition of the PM

Diverse studies have shown that more than 90% of the PM is emitted by residential combustion of firewood,

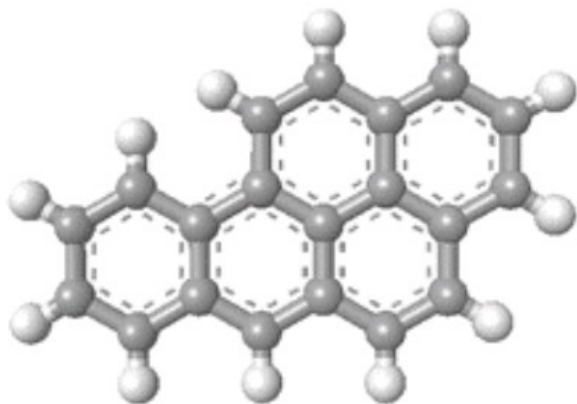


Figure 5 Structural model of Benzo(a)pyrene (BAP).

corresponding to PM_{2.5} [Chow et al., 2011]. On the other hand, the data obtained in the monitoring station shows that during the pollution episodes, PM₁₀ inhaled by the population is constituted in more than 90% for PM_{2.5}.

The sources of PM_{2.5} are eminently anthropogenic. The basic composition of these particles is elemental carbon (black carbon or soot), whose basic structure is similar to graphite, and that, in consequence is an excellent absorbent for a grand variety of organic compounds. This absorbent capacity is strengthened by the fact that the total surface area increases while the size of the particles decreases.

Among the compounds present in PM, the most notable are the polycyclic aromatic hydrocarbons (PAH's), known to be mutagenic and carcinogenic [Pufulete et al., 2004]. These PAH's are solely comprised of carbon and hydrogen. Within them, benzenic rings (aromatic rings with six carbons) are fused, in a number that varies between two and eight (Fig. 5). In this manner, the PAH's are a family of 500 compounds approximately, which are formed in the incomplete combustion of fossil fuels (coal, petroleum and derivatives) and biomass. This means that the PAH's are formed along with the PM. Of these compounds, the one that exhibits the highest toxicity, (and for that receives more attention) is the Benzo(a)pyrene(BAP). In the year 2005, the European Union fixed in 1 ng m⁻³ the maximum limit permitted for the annual concentration of BAP in PM₁₀. In general, PAH's are

compounds that are semi-volatile or of low volatility, and because of this are distributed among the PM and the gaseous phase of the atmospheric aerosol. It is observed that as the particle decreases in size, the amount of PAH's within the particle increases.

Chemical speciation of the atmospheric aerosol of Temuco and Padre Las Casas

Between August and September of 2008, the Environmental Chemistry Laboratory of Universidad Técnica Federico Santa María, led by Dr. Francisco Cereceda, in conjunction with the Air Quality Unit of the Universidad Católica de Temuco, carried out a campaign to determine the presence of PAH's in the urban atmosphere of Temuco [Cereceda-Balic et al. 2011].

The sampling equipment was located in Las Encinas, where the official monitoring of PM is carried out for Temuco. Four integrated samples were taken (24 h, in triplicate). Facilitated by the forecasting model of air quality that the Secretary of the Environment of the Araucania Region manages, the samples were taken on dates which elevated concentrations of PM were registered, as well as at the times when they were the highest.

During the sampling, cartridges with teflon filters were used to collect the PM_{2.5}, and Polyurethane foam filters to collect the gaseous phase of the atmospheric aerosol, in which PAH's are also found. These filters were sent to the laboratory, where they were subjected to extraction by toluene solvents. The volume of the extract was reduced first in rotavapor and after, in a controlled nitrogen current. The resulting concentration was purified in a column packed with silica, to be analyzed by gas chromatography mass spectrometry (GC-MS). 16 EPA-PAH's were identified and quantified, which are defined by the Environmental Protection Agency (US EPA) as representatives, based on their composition, toxicity and frequency of appearance. Within these, BAP is included.

The total concentration of PAH's found in the atmosphere of Temuco reached an average value

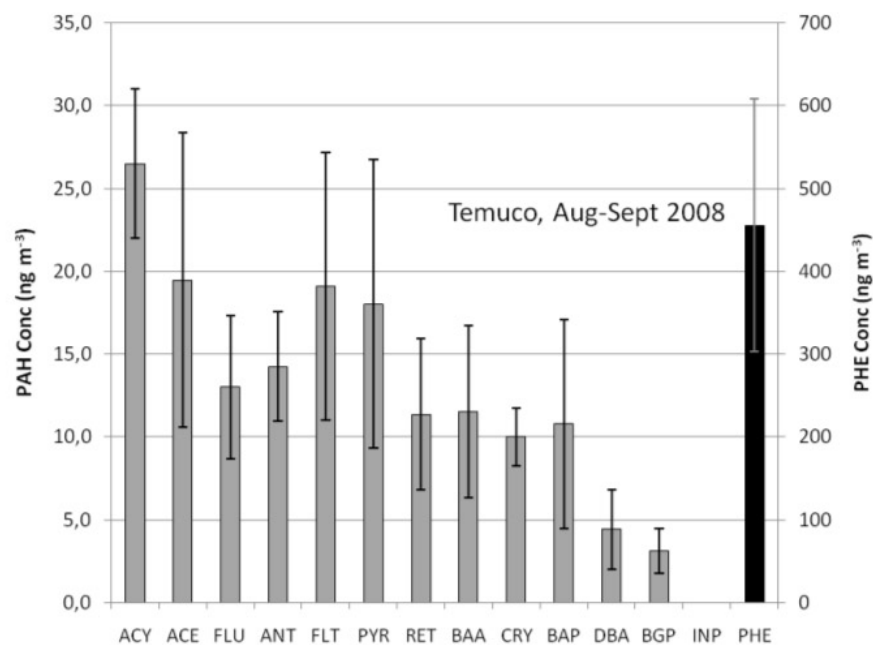


Figure 6 Average concentrations (n=4) of 16 EPA-PAH's, during the campaign of August-September of 2008 [Cereceda-Balic et al. 2011].

of 613 ng m⁻³, with a variability of 42%. In general, the concentrations found in the gaseous phase were three times higher than those found in the PM. This fact increases the potential damaging effect of these substances, due to that they enter easier into the organism. The average concentration of BAP was 10.8 ng m⁻³, which far surpasses the limits established by the European Union.

The seriousness of these results is evidenced in that the chronic exposure to these levels of PAH's, (considering an average lifespan of 70 years), increases 10 times the probability of contracting lung cancer, or testicular cancer in males.

Conclusions

Innumerable worldwide studies have demonstrated that there exists a significant association between the exposure to PM and mortality and morbidity because of respiratory and cardiovascular causes. Temuco and Padre Las Casas is not the exception. The studies about the short-term effects show particularly high relative risks, especially for the age group 65 and over. These results are explained by characteristics that it

presents the PM generated by the residential combustion of firewood. This source emits more than 90% of fine and ultrafine PM, constituted of elemental carbon and organic substances of elevated toxicity.

The data in this study suggests that in the urban atmosphere of Temuco the concentrations of polycyclic aromatic hydrocarbons - know mutagenic and carcinogenic substances - were many times higher than limits established in international regulation. In particular, the concentration of Benzo(a)pyrene (BAP) - the most toxic PAH - was ten times higher than the limit established by the European Union (1 [ng m⁻³]). From these results, it is predicted that the chronic exposition to PM will be the cause of diseases such as lung cancer, and testicular cancer in males.

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