A new porous hybrid material to reduce air particulate matter (PM)

This work concerns the demonstration of the efficiency of an innovative approach to produce a new sustainable porous material, named SUNSPACE (SUstaiNable materials Synthesized from by-Products and Alginates for Clean air and better Environments), for particulate matter (PM_{10} and $PM_{2.5}$) trapping using industrial by-products. Environmental and economic benefits are expected to be obtained by the proposed method.

The European Environment Agency estimated that in the 2012–2014 period 50–63% and 85–91% of the urban population in Europe were exposed to levels of PM_{10} and $PM_{2.5}$ (respectively) which exceeded the recommended World Health Organization (WHO) annual limits (PM_{10}: 20 µg/m^3 and $PM_{2.5}$: 10 µg/m^3). In the same report it was extenuated that 467000 premature deaths in Europe could be attributed to $PM_{2.5}$ (PM less than 2.5 µm in aerodynamic diameter) in 2013. PM pollution due to fine particles is particularly harmful since fine PM can penetrate human bronchi and lungs owing to the small particle size.
The European Commission encourage the research of innovative low-cost materials capable to reduce the concentration of particulate matter in urban areas. These solutions should be design-driven, innovative, affordable and sustainable.
To meet all these requirements, we developed a nature-inspired solution deriving from a green and sustainable, process and technologies (as formulated in the Green chemistry). We called this chemistry approach that want to link Green Chemistry and Remediation “Azure Chemistry”.

The main objectives of this project are:

1. Waste reduction and creation of sustainable materials;

2. Production of new material (SUNSPACE) from industrial by products for air quality monitoring;

3. Uses of reliable and simple method to analyze chemical composition of PM and heavy metal for a fast screening and environmental monitoring;

4. Comparison of SUNSPACE with respect to leaves (the most sustainable, low-cost and effective solution to PM capture);

5. Application of SUNSPACE as plaster.

The activity is provided in the following tasks:

- Synthesis of material: SUNSPACE is obtained by using low cost amorphous silica (silica fume), sodium alginate with calcium iodate, as binder and sodium bicarbonate, as pore former. For the pores creation low temperature is required between 70-80 °C;

- Material characterization: structural, morphological, porosimetric and mechanical characterizations of SUNSPACE are performed by X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Trasmission Electron Microscopy (TEM), N_2 physisorption, pore size distribution and B3B test;

- Experimental tests to analyze the ability of porous material to PM capture.

The novelty of this method consists in the reuse of industrial waste, producing a sustainable product from environmental and economic point of view. This procedure has been developed and a patent is submitted. By this method, silica fume is mixed with a highly gelling biopolymer, which acts as a resin, alginate and sodium bicarbonate.

The key features of this approach are: its good stability even in room temperature and its versatility, which means that changing the ratio of each components, 3D printing may be performed.

N_2 physisorption isotherm and pore size distribution suggest the presence of ink-bottle shaped pores, suitable for fine and ultra-fine PM capture.

At the first time, studies to evaluate the sequestration capability of porous material are performed in five different environments: in a steel making industry, in the laboratory, in a gateway, in the highway, and in the courtyard area of Brescia (Italy). The amount of collected PM is estimated from elemental chemical analysis made by Total reflection X-Ray Fluorescence technique (TXRF).

Subsequently, SUNSPACE capability in ultrafine PM entrapment is demonstrated by the use of monodispersed titanium (TiO_2) and Iron (Fe_3O_4) nanoparticles. To test the capability in ultrafine particles trapping, and to verify the particles penetration depth into SUNSPACE, a sample is put in contact with Titanium or Iron nanoparticles. The idea was not only to verify the capability to PM entrapment but also to better understand the possibility to trap particles with diameters in the range of few nanometers and the thickness of the material involved in their capture. In particular, the use of monodisperse and chemically uniform particles would allow to discriminate the porous material and nanoparticles in SEM and TEM analysis.

The ability of SUNSPACE to trap PM was also compared with that of leaves. SUNSPACE can capture more than 3 mg/cm^2 of ultra-fine PM (more than two order of magnitude higher than the amount of fine particles that can be accumulated by leaves). This means that employing SUNSPACE to cover for example only roof tiles, for a city like New York, where roofs globally occupy a surface of 92 million of m^2, about 2700 tons of air particulate matter may be trapped only by roof.

SUNSPACE can be applied as a coating on available urban infrastructures: the possibility to integrate SUNSPACE in existing building industry (TRL level 7) was demonstrated by its application as a plaster.

Finally, SUNSPACE is designed to be regenerated, after PM capture, simply by rainfall. The discharge water can be collected by the urban wastewater collection system (for example with wastewater deriving from street washing) to be conveyed at the urban wastewater treatment plant, with no additional impacts.