Catalytic gas purification

Safe Energy

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Dr. Agata Łamacz, an assistant professor at the Centre of Polymer and Carbon Materials, Polish Academy of Sciences, is currently working on obtaining hybrid materials combining carbon nanotubes and metals and their applications in catalysis. She received the Maria Skłodowska-Curie award for her work dealing with the catalytic purification of gasses emitted during the combustion and gasification of coal.

The energy sector is about more than just the electric power in our wall sockets and keeping our homes warm. It is the foundation on which the economy rests, and also a crucial part of the way we affect the environment. To better protect the natural environment, we need, for instance, to develop active catalysts that can change harmful chemical compounds into neutral, or even useful ones

The ongoing advancement of technology brings great benefits to humankind, but our increasing comfort often comes at the price of polluting the natural environment, especially the air that we all have to breathe.

One of the main sources of energy is coal, and its combustion releases ash, heavy metals, and toxic substances like sulfur dioxide (SO_2) and nitrogen oxides (NO_x). The latter are involved in causing acid rain, which have negative impact not only on living organisms but also on infrastructure. A significant share of Poland's nationwide emission of harmful gases comes from coal-fired power plants, which burn coal to generate the power needed to heat our homes and keep industry running. Poland's most polluted region is Upper Silesia, home to the largest numbers of mines, power stations, and industrial plants. There are, naturally, standards regulating the emission of harmful substances into the atmosphere; failing to abide by them entails serious financial consequences, which are then paid for by the average Pole in the form of higher coal and energy prices. And so, reducing emissions of harmful gases and ash is a necessity from both the ecological and economic points of view.

Apart from releasing toxic substances, coal combustion above all leads to huge emissions of carbon dioxide (CO_2), considered the most important factor contributing to climate warming. Despite the controversy that surrounds global warming, EU directives clearly mandate reductions in CO_2 emissions, and that in turn necessitates the use of different carbon harnessing solutions. An alternative to conventional carbon combustion is offered by Clean Coal Technologies, a name applied to numerous processes and methods of harnessing coal that reduce the negative environmental impact of its combustion.

One such technology involves gasifying coal into a synthetic gas called "syngas," a mixture of hydrogen and carbon monoxide. Syngas is then used to produce energy or chemicals. Unfortunately, the gasification process generates tar compounds that significantly pollute the post-process water. Moreover, they can condense or polymerize inside the pipes of the gasification facility, clogging them, reducing the effectiveness of the process and significantly increasing costs. Like the nitrogen oxides released in the process of coal combustion, these tar compounds are undesirable products and have to be removed. There are many gas purification methods, but the best effects are achieved by catalytic processes.

Speed it up

The term "catalysis" was introduced into chemistry in 1835 by Jöns Jacob Berzelius, and since then the phenomenon has been systematically studied by many scientists. Fritz Haber, for instance, developed a method of obtaining ammonia directly from nitrogen and hydrogen in the presence of a catalyst. His discovery made it possible to produce artificial fertilizers and contributed to the fight against hunger in the first half of the 20th century. Nowadays catalytic reactions are utilized to synthesize compounds used to produce plastics, paints, fabrics, drugs, etc. For many years, catalysis has also played a huge role in environmental protection. We can safely say that catalytic reactions find application in every field of life. Even within our bodies, countless numbers of processes catalyzed by enzymes take place every day. A catalyst is a substance that is not consumed in a given reaction, but speeds it up. Very often it also allows a given reaction to take place at a much lower temperature.

If a catalyst and the reaction environment are in different phases, for instance with the catalyst being a solid and the reaction taking place in gaseous phase (as in the case of nitrogen oxide removal or decomposition of tar compounds), this is called heterogeneous catalysis. Here chemical reactions occur on the surface of the solid, or more precisely at the gas-solid interphase. The detailed study of such phenomena is extremely important for properly "designing" a catalyst for a given reaction. Heterogeneous catalysts very often (though not always) consist of a support material on which an active phase has been deposited, the latter being responsible for speeding up the given reaction. The role of the support is to ensure a large area of contact between the reaction mixture and the active phase. Sometimes the support material itself also exhibits catalytic properties.

Finding the right recipe

My work has used a ceria-zirconia mixed oxide ($CeZrO_2$) as a support, on which I deposited various metals (including copper, cobalt, and nickel). This support material has exceptional physiochemical properties, causing interesting phenomena to occur on the surface of the catalysts. The sheer number of such phenomena was sometimes dizzying, but that is precisely what made the research so interesting and offered a lot of satisfaction. Especially when it turned out that the catalyst demonstrated high degrees of activity and selectivity to the intended products and remained stable through a long reaction time.

The first part of my work dealt with selective catalytic reduction (SCR) of nitrogen oxides. This method is one of several that enable harmful nitrogen oxides to be transformed into chemically neutral nitrogen (which is, after all, the main component of our atmosphere). The breakdown of nitrogen oxides is carried out using various reducing agents, such as carbon monoxide (CO), ammonium (NH_3), and hydrocarbons (C_nH_m). Because the latter are present in the exhaust gasses from coal combustion, they seem to be the most favorable option for SCR - there is no need to add additional substances to the gas stream, and the uncombusted hydrocarbons break down into carbon dioxide and water steam. This work was carried out under the Polish-French EUREKA project called "Abatement of N_2O and NO_x from Industry Plants and Fossil Fuel Combustion Devices over Novel Catalysts."

Next I got involved in researching the catalytic decomposition of tar compounds, under the project entitled "Chemistry of the Prospective Processes and Products of Coal Conversion" funded by the Polish Ministry of Science and Higher Education. The tar produced by coal gasification is a mixture of hydrocarbons (mainly aromatic ones) of varying reactivity. Hence the tar produced depends on many factors, such as the type of gasified coal or the conditions under which the process is carried out. Tar compounds can be broken down, for instance, in a catalytic steam reforming reaction. After steam is added to the raw output gas from coal gasification, it is possible for undesirable tar compounds to be reduced to syngas.

When I try to explain the most important outcomes of my work, I know that I cannot limit myself solely to finding an active catalyst for the decomposition of tar compounds, which has successfully passed recent testing on a pilot-project scale and stands a chance of being applied in industrial processes. Any list of successes would also have to include the projects that I was able to carry out near the end of my doctoral work thanks to funding from the Polish Ministry of Science and Higher Education, the Polish National Science Centre, and also the Marie Skłodowska-Curie Thesis Award, which I received from the French ambassador to Poland, Pierre Buhler. This gave me a sense that my work was being noticed and appreciated. Moreover, something such lists typically fail to mention, but which is very important to me, is recognition of the numerous acquaintances and friendships I had the good fortune to forge with the magnificent people I encountered in my work, at research conferences, and during my visits to Pierre and Marie Curie University in Paris, where I carried out some of my research. They were oftentimes the "catalysts" who gave rise to any successes that might be ascribed to me. ■

Further reading:

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French Embassy in Warsaw

Dr. Agata Łamacz receiving the Marie Skłodowska-Curie Thesis Award from Pierre Buhler, the French ambassador to Poland