Wood-burning stoves: Combining electrostatic precipitators and catalytic converters is the best way to reduce pollutants

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The flue gases underwent chemical and physical tests at RWTH Aachen University. Credit: Johann Hee

In Germany, there are millions of small firing systems; wood-burning stoves for domestic use in which logs are burned. In the process, a lot of particulate and gaseous pollutants are released into the atmosphere: ultrafine soot particles, carbon monoxide, highly volatile organic substances such as formaldehyde, polycyclic aromatic hydrocarbons (PAHs) and many more. The number of substances released runs into the thousands, and some of them affect each other, which makes them even more hazardous.

In Germany, the First Federal Immission Control Ordinance sets limit values, at EU level the Ecodesign Directive. To reduce pollutant emissions, stoves are fitted with abatement devices, such as electrostatic precipitators or catalytic converters. The electrostatic precipitator charges the particles in the flue gas so that they are precipitated in the flue pipe. The catalytic converter converts toxic gaseous substances into non-toxic ones. In this way, carbon monoxide and hydrocarbons are transformed into carbon dioxide (CO_2) and water, for example.

Although studies on catalytic converters and electrostatic precipitators have already been published, these have only looked at a few pollutants in the flue gas. In practice, catalytic converters and e-separators have so far rarely been installed. Until now, it has not been clear how effective these technologies really are. The collaborative project "TeToxBeScheit" has now been able to close this knowledge gap.

Scientists from four institutes have investigated to what extent catalytic converters and electrostatic precipitators separately and in combination reduce pollutant emissions and what protective effect this has on humans and the environment. The Unit of Technology of Fuels at RWTH Aachen University (TEER) coordinated the project. It built the test stand for taking the flue gas and particle samples and conducted the chemical and physical experiments together with Uniklinik RWTH Aachen.

The Medical Center—University of Freiburg was responsible for the human toxicology experiments and Goethe University Frankfurt for the ecotoxicological ones. The latter were conducted by a team from the Department of Evolutionary Ecology & Environmental Toxicology at the Institute of Ecology, Diversity & Evolution of Goethe University Frankfurt, led by Professor Henner Hollert, Dr. Sabrina Schiwy and Marc Wollenweber.

Professor Hollert describes what is special about "TeToxBeScheit" by explaining, "It is the first study on pollutants from wood-burning stoves with an integrated approach that goes far beyond the chemical analysis of individual substances. Together with the other partners, we have taken a very close look at the flue gas, the particulate matter emissions and the effect of the abatement devices, not only the chemical and physical side but also the human toxicology and ecotoxicology side, that is, the effect of the pollutants and combinations of them on humans and ecosystems.

"This effect-based analysis is also able to corroborate the adverse effect of previously unknown pollutants and pollutant mixtures and has so far not been conducted in this way in similar studies."

Environmental toxicologist and research associate Marc Wollenweber used cell cultures and aquatic test systems to examine the pollutants from the wood-burning stoves, as in nature pollutants also enter water bodies, for instance when rain leaches them out of the air. Together with TEER and the Medical Center—University of Freiburg, he used wash bottles on the test stand to simulate this leaching. Wollenweber then looked at how three aquatic model organisms reacted: algae, water fleas and fish embryos.

In the water with untreated flue gas, the toxicity was clear to see. The organs of the fish embryos—an alternative method to animal experiments with fish—were damaged, the water fleas died, and algae growth was inhibited. With an upstream catalytic converter, however, no adverse effects were seen and the pollutant load of the aquatic systems could be substantially reduced. The chemical and physical measurements corroborated this result from the biological experiment.

The electrostatic precipitator, on the other hand, proved to be less effective in the firebox. Only when the device was installed at a greater distance from it did the toxicity decrease. The reason for this is that certain substances only bind to particles in the flue gas once it has cooled down and the particles can be removed.

For the human toxicology experiments at the Medical Center—University of Freiburg led by Dr. Manuel Gracia-Käufer, a cell-based model of a lung was used to evaluate the effect of inhaling the flue gases. This in vitro exposure method is currently the most advanced of its kind. In such experiments, the lung cell cultures grow on the boundary layer between the gas phase and the liquid phase, thus mirroring the conditions in the human lung.

The airborne pollutants flowed over the lung cells from the side facing the air, like when inhaling flue gases. The scientists then measured whether, for example, the genome changed as a result of the (toxic) load during exposure. The outcome was that the catalytic converters initially performed better than the electrostatic precipitators vis-à-vis human toxicology as well. This was again due to the fact that electrostatic precipitators, although they substantially reduce the particulate load, only neutralize gaseous pollutants from the flue gas to a limited extent.

Accordingly, for Dr. Sabrina Schiwy, team leader in the Department of Evolutionary Ecology & Environmental Toxicology at Goethe University Frankfurt, the catalytic converters are clearly the "winners." She considers them to be "universally effective," they could reduce highly reactive substances that penetrate our lungs in gaseous form or as fine particles. They can be retrofitted for a small sum, about €400.

The immediate effect of the electrostatic precipitators vis-à-vis ecotoxicology and human toxicology is initially less obvious, but they are nevertheless indispensable as additional abatement measures because (especially in the case of a chronic load) they reduce hazardous particulate matter emissions by up to 95%. Electrostatic precipitators thus have an effect in an area not covered by catalytic converters. TEER discovered this important aspect during its experiments.

The study also examined the effect of the two technologies in combination. As a consequence, Wollenweber recommends that wood-burning stoves be equipped with both in the future. The electrostatic precipitator should be installed upstream of the catalytic converter so that it removes the particles first. The catalytic converter then takes care of the gaseous substances.

But what do the results mean for the First Federal Immission Control Ordinance, which only sets limit values? Wollenweber says, "We are calling for the limit values to be adjusted to the state of the art for abatement measures so that no more stoves are sold and installed without them."

More information: Peter Quicker et al, "Kombinierte technische und toxikologische Bewertung von Emissionsminderungsmaßnahmen für Scheitholzfeuerungen (TeToxBeScheit)" (in German) (Combined Technical and Toxicological Evaluation of Emission Abatement Measures for Wood-Burning Stoves) (2023)

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