f exhaust air flows from industrial processes are polluted with strong-smelling or harmful organic compounds, these compounds must be removed. The Volatile Organic Compounds (VOC) guideline, which sets stricter limits for emissions of highly volatile gases, requires this. Metalworking companies, paintshops, catering kitchens or other production companies can now use a new exhaust gas purification process to remove low concentration VOCs efficiently and cost-effectively from large quantities of exhaust air. The new system was developed with the support of the German Federal Ministry of Economics and Technology. It combines electrically regenerable activated carbon adsorption with a low temperature combustion of the desorbed and concentrated organic exhaust components. As the pollutants are highly concentrated, the remaining desorption volume flows are very small, meaning that a small downstream treatment system is sufficient.

The adsorption of volatile organic compounds by activated carbon fibre cloth combines the advantages of a rapid mass transfer with the disadvantages of low capacity. Frequent regeneration via desorption is a requirement for the development of a technically usable process. Electrical direct heating of carbon fibres for desorption is particularly interesting because the energy input is decoupled from the air flow; the desorption air flow which is far smaller than the adsorption air flow allows extremely high concentration ratios to be achieved. The new process excels with energy consumption half that of thermal reactors. The purified exhaust air can also be returned, entirely or partially, to the production hall.

The new process with activated carbon fibres is already used by one industrial partner in modularly structured large-scale technical systems, to remove hydrocarbons effectively and economically from exhaust gas flows.
In the first process step of the exhaust air purification system, the VOCs are adsorbed in activated carbon filters. The structure and functional principle of the new, directly electrically heatable adsorber are shown in Fig. 4. After desorption, the highly concentrated VOCs are combusted as a minor gas flow in the downstream thermal reactor, or treated otherwise. See the flow diagram Fig. 3. The process reaches a separation efficiency of over 98%.

The advantage over competing solutions such as thermal reactors, biofilters or adsorber wheels is that the purified exhaust air can be routed back into the production halls in many applications, as its temperature and humidity is virtually identical after the adsorption process. This allows significant energy savings for heating and climate control. Activated carbon fibre (ACF) cloth and granulated activated carbon (GAC) were studied as adsorber materials, as were newly developed catalysts for low temperature combustion.

Low temperature combustion with newly developed catalysts
A further objective of the project work was to develop a catalyst which combines as low a working temperature as possible with excellent long-term and toxic stability, and only forms traces of nitrogen oxide from amine nitrogen. However, the new catalysts and a commercial platinum catalyst aged unexpectedly fast and the project was unable to develop a material which was sufficiently resistant to allyl sulphide, the sulphurous ethereal oil of onions and garlic. Until the catalyst problem has been solved satisfactorily, a mini thermal reactor operated autothermically guarantees low-NOx combustion. However, this increases the overall investment costs by approx. 10 – 15%.

Fibre and granulated filters
VOC adsorption with activated carbon fibres (ACF)
Exhaust air systems can be made more compact by using activated carbon fibres (Fig. 2), as they have a far greater specific surface than granulated carbon. As the concentration of pollutants in the regeneration air is very high, a far smaller combustion system is sufficient. This significantly reduces the operating costs. For thermal post-combustion, a far smaller air flow is sufficient compared with standard external heating.

To regenerate the loaded filter, the activated carbon fibres are electrically heated to the required desorption temperature by the automatic process control system. Direct heating also removes difficult to desorb compounds from the carbon. The activated carbon fibre system has high intrinsic safety, as only approx. 20 kg of carbon is used per module, instead of tonnes of granulated activated carbon.

Practical examples of electrically heated carbon fibres

Exhaust air from a pharmaceutical supply company
An experimental system concentrates exhaust air containing silicone via carbon fibres, and routes it through condensation for recovery. A capital return period of 2 years is forecast, as the recovered silicone is a valuable compound.

Exhaust air from a film maker
In a newly installed filter system, exhaust air containing dichloromethane is concentrated and fed into the company’s own recovery system. Only this measure allows the company to meet the requirements of the authorities.

Exhaust air in a paintshop
In an experimental system, exhaust air was concentrated with less than 100 mg/m³ VOC. The operating costs for the process planned for 70,000 m³/h were considerably lower than all other alternatives.
Adsorption with granulated activated carbon

The applications of granulated activated carbon adsorbers were tested in a follow-on project funded by the Deutsche Bundesstiftung Umwelt (DBU). Granulated activated carbon is particularly suitable for treating strong-smelling, organically low-polluted exhaust air from production, e.g. from foundries, as well as amine-containing exhaust air, and even remains economical when the carbon is blocked by non-desorbable reaction products within 6 to 12 months, as the price of granulated activated carbon is only one hundredth of the price of ACF.

Fig. 6 shows possible applications and differences between activated carbon fibre and granulated activated carbon filters.

Cost comparison

The new processes with activated carbon fibre cloth or granulated activated carbon for strong-smelling exhaust air, hall exhaust air, building supply air, and diffuse exhaust air sources, in which the raw gas concentrations are usually considerably below 100 mg/m³, are particularly interesting. Compared with other processes such as thermal reactors or biofilters, they become more cost-effective the lower the exhaust air concentration is, and the greater the odour and air quantity. It is particularly advantageous when much of the purified exhaust air can be fed back into the building, as this is not possible in the competing processes. Fig. 5 shows how energy efficient the GAC system works with low raw gas concentrations based on the annual overall energy consumption, compared with regenerative thermal post-combustion.

In terms of ecology, biofilters are the most effective of all processes, even compared with ACF carbon, largely due to the extremely low specific energy level required. However, they require a great deal of floor area and burden the area with great surface loads. Also, it is difficult to achieve stable degradation degrees of over 90%.

This restricts industrial applications. Other competing processes include adsorption using granulated activated carbon with external regeneration at the premises of a service provider, concentration via concentrator wheels or fixed beds and oxidation without prior concentration, but with heat recovery, in particular in the form of regenerative thermal combustion (RNV), but also as catalytic oxidation, depending on the mixture of substances.

In this area, the electrically heated adsorbers are positioned with higher investment costs than the traditional techniques, probably also partially due to the fact that the adsorber modules are not yet manufactured in mass, and are therefore not optimised, but with significant savings in operating costs, which are all the more significant, the higher the price of primary energy rises. In the applications with problem components studied over extended periods with pilot systems, such as foundries, it was found that using catalytic post-combustion does not make sense, as even standard platinum catalysts do not reach combustion temperatures of 330 °C or below constantly. Also, catalyst poisons sulphur and amine can occur as part of odorous substances.

Practical examples of fibre and granulated filters

Exhaust air in a catering kitchen

The ACF pilot system was used to treat exhaust air from a catering kitchen. The odorous substances were retained safely, even at the end of the experiments. The long service life of the adsorbers is advantageous for the system operating costs. During the experimental phase, the total conversion of the catalyst decreased constantly from 81% to 52%, whereby the aging was temperature-related and not substance-specific.

Purification of hall air in a foundry

Purification of exhaust air from the hall of an aluminium foundry was studied with a GAC pilot system. The concept for the large-scale system is designed such that the hall air is purified in a system with 6 modules, whereby one filter is regenerated each time. Of the 40,000 m³/h of exhaust air generated each hour, 32,000 m³/h are returned to the hall after treatment. The system achieves forty-fold enrichment, leaving only a regeneration gas quantity of 1,000 m³/h for thermal post-treatment.

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<table>
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<tr>
<th>Cost comparison</th>
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<tbody>
<tr>
<td><strong>Activated carbon fibre cloth</strong></td>
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<tr>
<td>Suitable for</td>
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<tr>
<td>Exhaust air flows (T&lt;40 °C, ϕ &lt; 60%), VOC concentrations &lt; 100 mg/m³, boiling point up to 230 °C</td>
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<tr>
<td>Production hall exhaust air from the foodstuffs industry, aroma industry, chemical and metalworking industry, paintshops</td>
</tr>
<tr>
<td>Supply air from buildings, air return rates of up to 90% in air conditioning systems</td>
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<tr>
<td>Regenerable automobile interior air filter</td>
</tr>
<tr>
<td>Properties, advantages</td>
</tr>
<tr>
<td>Deposition rate from 95 to 99.9%</td>
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<tr>
<td>Heat supply and substance transport decoupled</td>
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<tr>
<td>Enrichment up to 50 to 100 times to in general 25% of the LEL possible. For regeneration under inert gas or in vacuums, enrichments up to a factor of 1,000 are possible</td>
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<tr>
<td>100 times higher mass transfer speed than GAC</td>
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<td>Very compact systems possible</td>
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<tr>
<th>Granulated activated carbon</th>
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<tbody>
<tr>
<td>All exhaust air flows (T&lt;40 °C, ϕ &lt; 60%), VOC concentrations &lt; 300 mg/m³, boiling point up to 230 °C</td>
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<tr>
<td>Production hall exhaust air from the foodstuffs industry, aroma industry, chemical and metalworking industry, paintshops</td>
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<tr>
<td>Supply air from buildings, air return rates of up to 90%</td>
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<tr>
<td>Solvent recovery under vacuum conditions in the circuit (planned, simulation successful)</td>
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<tr>
<td>Deposition rate of over 98%</td>
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<tr>
<td>Heat supply and substance transport decoupled</td>
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<tr>
<td>For vacuum desorption: Significantly higher desorption gas concentrations upstream of the condenser, lower condensation temperatures, value stays safely below LEL in the adsorber for vacuums under 100 mbar</td>
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<tr>
<td>Longer loading service lives due to larger quantity of carbon, longer desorption times, better utilisation of the thermal post-combustion</td>
</tr>
<tr>
<td>Even profitable if the carbon has to be externally reactivated after 6 – 12 months</td>
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</table>
Conclusion and prospects

The exhaust air from catering kitchens, paintshops, chemical or metal industries can be purified energy-efficiently with the new process. The new systems trap highly volatile organic compounds like solvents and aromas, and are particularly suitable for great volume flows with low pollutant concentrations. They already enrich low-volatile compounds up to fifty times. Researchers assume that enrichments up to 1,000 times can be reached for specific applications under inert gas or vacuum. The collected pollutants are adsorbed via electrically regenerable activated carbon and subsequently combusted autothermically. After desorption, only a minimal gas flow has to be treated, as the pollutants are very highly concentrated. This allows a small downstream treatment system to be chosen, and a major part of the pured exhaust air to be routed back into the production buildings. Therefore it is also conceivable to integrate electrically regenerated ACC in building air conditioning systems. This allows stable separation efficiency of over 98% for VOC, odours and ozone as well as significant heating energy savings.

The new catalysts developed in the project for low temperature combustion still aged too quickly due to compounds containing sulphur and amine, and then no longer worked well enough for cost-effective operation. Enrichment or separation of substances can become further applications for ACC electrical adsorbers, whereby, for example, optimal temperature and time programs can be run for extracting solvents from the exhaust air with electrical heating. Process simulations for the studied processes promise cost-effective and technically interesting prospects, in particular in the area of solvent recovery with electrical regeneration under vacuum. However, further development work is required for large-scale technical applications. The modelling of the overall system for adsorbent purification of exhaust air in a computer program for system design and operating parameter optimisation also appears to be realistically usable for the simulation of systems with other applications.

Project Funding
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Project Number
0327338A

IMPRINT

ISSN
0937 – 8367

Publisher
FIZ Karlsruhe
76344 Eggenstein-Leopoldshafen
Germany

Reprint
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