MODULAR AIR QUALITY SYSTEM FOR INTERIOR COMFORT

As traffic volumes and the associated burdens on drivers increase, the need for a relaxing, rejuvenating atmosphere in the vehicle becomes ever greater. The five-stage air quality system from Behr can meet these requirements in full, right down to generating a truly experienceable atmosphere of wellbeing in the vehicle interior of passenger car and truck, with ionized air and a selection of fragrances for every preference.
INTRODUCTION

High air quality in the vehicle is possible only through the implementation and interplay of the technologies detailed in the "air quality steps" in 1, which adopts and promotes a bottom-up approach to meet the requirements. For instance, ionization and fragrancing only make sense if the air has already been largely purged of particles, harmful gases, odors, and to some extent microorganisms, that means through filtration, sensor technology, the evaporator surface materials BehrOxal or BehrOxal nano.

The primary focus of this article is on air ionization and fragrancing. The preceding stages of the air quality steps are only briefly addressed.

FILTRATION, SENSOR TECHNOLOGY, BUT ALSO BEHROXAL AND BEHROXAL NANO

Modern vehicle cabin filters, pure particle filters, and hybrid filters (particle filters with active carbon layer), are designed in accordance with DIN 71460. The particle collecting properties of particle filters are analyzed using test dusts, while the absorptive capacity of hybrid filters is examined using test gases.

Harmful gases (CO, NOx) as found in diesel and gasoline exhaust gases, for instance, are detected using air quality sensors. If the concentrations of these gases increase substantially, the signal transmitted by the sensor prompts the climate control system to switch automatically to recirculated air mode to avoid overloading the filter and to prevent a filter breakthrough with harmful gases entering the vehicle cabin.

The BehrOxal surface treatment modifies the aluminum surface of evaporator, giving it hydrophilic properties. Any accumulating condensation forms a thin, rapidly draining film of water purging impurities together with microorganisms and their nutrients from the surface instead of producing large slowly drying water droplets. The optimized evaporator design promotes the draining of water, enabling the surface to dry more quickly after operation. This, in turn, reduces the prevalence of microbial growth, for which water and nutrients are required. It is also possible to apply biocide coatings to the evaporator surface.
However, field studies have revealed that the application of conventional bio-cide coatings is largely ineffective against odor-producing germs. Furthermore, these products are quickly washed out by condensate, meaning that any effect they have is short-lived at best. The new BehrOxal nano coating has been developed for this reason. This consists of a polyurethane lacquer coating containing an abrasion-proof and leach-resistant nanoscale biocide that destroys odor-producing germs.

IONIZATION

The ionization of air, a widespread practice in households in Asia, is becoming more widely used in motor vehicles as well. However, simple modification of domestic ionization equipment is not sufficient to meet the stringent requirements of the automotive industry in terms of reliability, operational safety, and the minimization of ozone production. For this reason, Behr, together with the world-renowned electronics supplier Samsung, as development partner, has developed an ionization module specially for automotive applications. This module generates only a negligible amount of ozone. The device enables the vehicle occupants to choose between two operating modes (Clean and Relax) that produce different ion types in high concentration.

CLEAN OPERATING MODE

The functional principle of the “Clean” mode involves the generation and application of high voltages to a ceramic cathode and needle-shaped anode using a special electronic system. First, hydrogen cations are generated on the cathode from water vapor in the air, and these are subsequently reduced to atomic hydrogen at the anode. Superoxide ions (O2-) are also formed at the anode and react with the hydrogen atoms to produce hydrogen peroxide ions (HO2-). These anions settle on microorganisms present in the air (bacteria, viruses, fungi, or spores) and deproto-nate their protein envelope, to a certain degree impairing their biological function. The microorganisms, although still present in the air, lose their pathogenic effect. They are “deactivated” as it were, since the damage to their protein coating removes their capacity to invade human cells.

A renowned biotechnical institute demonstrated this practice of “deactivation” using the bacterium Staphylococcus aureus as an example. In the laboratory experiment, the count of this bacterium was reduced by 97 % within 20 min using ionization and the product described above. The number of influenza viruses dropped to one thousandth (0.01 %) compared with the virus count without ionization (10 %) in just one hour in the test chamber. A competitor product tested in the same way achieved a reduction only to approx. one tenth (1 %).

The efficacy for various pathogens and allergenic agents examined by external institutes. However, determining efficiency under laboratory conditions is not enough in itself. For instance, tests conducted on a used vehicle (two air samples taken daily, over six consecutive days) revealed a reduction in molds by up to 90 % (average 65 %) and in bacteria by up to 60 % (average 35 %). This shows that the technology is also effective in a real vehicle environment, even though test conditions in this respect are much more difficult and less well-defined than in a laboratory.

Additionally, the intensity of odors produced within the vehicle, such as from

| MICROORGANISMS / GERMS | EFFECTIVENESS | CONFIRMED BY |
|------------------------|---------------|--------------|
| Influenza virus type A (flu) | 99,7 % / 99,6 % | Kitasato Environmental Science Center / Yonsei University |
| Corona virus (Sars virus) | > 99 % | Kitasato Medical Center |
| Yellow micrococcus, coliform black mold, green mold | 99,9 % | Korea Consuming Science Research Center |
| Allergenic agents from house dust mites / cats / dogs | Effectiveness verified | British Allergy Foundation (BAF) |
| Methicillin-resistant Staphylococcus aureus (MRSA) | 99,9 % | Kitasato Environmental Science Center |

The S-Plasma ionizer module from Behr/Samsung for vehicle interiors removes their capacity to invade human cells.

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Additionally, the intensity of odors produced within the vehicle, such as from
cigarette smoke, is reduced. And in trials, involving two groups of participants, each with 50 persons, fewer cases of eye distress were recorded in the group with ionization as compared to the control group without ionization. These trials were conducted in an urban traffic environment as early as the 1990s. Neither of the two groups knew about the ionization. The evaluation also recorded a significant increase in driver vigilance in test drives featuring ionization. The report concerning these trials concluded with the following sentence: “Thus existing thermal and air quality conditions in vehicles have measurable effects on the productivity of drivers” [1].

**RELAX OPERATING MODE**

The “wellness effect” produced by the air revitalization of the “Relax” mode is based on an increased concentration of negatively charged ions (oxygen anions). Their positive effects on vehicle occupants have been demonstrated through observation and surveying of participants in test drives, and through psychological and medical testing. The results indicate a statistically significant improvement in reaction time tests. The participants reported feeling more capable, and found it easier to concentrate than in similar controlled situations without oxygen anions [2].

Medical examinations also showed reduced levels of the stress hormones cortisol, serotonin, adrenalin, and chromogranin A in the blood, urine, and saliva [3, 4].

The improvements are dependent on the individual sensitivity of the probands and the concentration of negatively charged ions achieved through ionization. A provides a comparative summary of data produced for various ionization units under standardized conditions on an in-house test bench. The data clearly indicate that, at $5 \times 10^6$ ions per cm$^3$, Behr’s own unit achieves the highest concentration of ions with a minor amount of ozone. For comparison, the following values represent naturally occurring concentrations of negatively charged ions (1 per cm$^3$):

- waterfall, forest: 50,000
- mountains, coast: 5000
- rural areas: 700 – 1500

The ion concentrations recorded in the vehicle (driver/passenger head area) with ionization correspond to those of mountain and coastal regions. Compared with measurements of ion concentrations taken in otherwise non-ionized vehicle cabins, this represents an enhancement by a factor of 100, meaning a significant increase in the concentration of negatively charged ions is actually possible in vehicles.

**SAFEGUARDS AGAINST OZONE FORMATION**

Also shows that the Behr module exhibits the lowest ozone level. This is achieved using a specific combination of electric high voltage, a tailored electrode geometry, electronic control, and coordinated, aerodynamic integration. The result is a maximized ion count with a minimum of ozone. B illustrates the application oriented test assembly used to produce the laboratory measurements. Standard distances between the outlet of ionized air at the vents and the heads of the front-seat passengers are deemed to be in the 50 to 80-cm range. C shows that, at a distance of 50 cm between air outlet and measurement probe, the increase in ozone concentration due to the process of ionization (measured in “Clean” mode) is extremely low, and is far below the odor threshold (40 μg/m$^3$). Values at distances of 75 and 100 cm are close to the limit of detectability, and exhibit no difference between activated/deactivated ionizer.

In-vehicle measurements have verified these laboratory results, recording an entirely harmless ozone concentration in the vehicle interior (likewise measured in “Clean” mode). This value, produced with doors closed and ionization system activated, is close to the detection limit of the measurement device (0.5 ppb), and is therefore significantly below values for external air, as illustrated in D. Figures on the day were more than a factor of 10 below the public ozone warning level (240 μg/m$^3$). In results of a 24-hours measurement conducted in recirculated air mode, the ozone level also remained at the limit of detectability. These findings verify the absence of ozone enrichment in
the vehicle cabin, even with extended duration of ionization. Use of the ionization module therefore has no relevant impact on in-cabin ozone concentration.

APPLICATION OF THE IONIZATION MODULE

It is vital for the effectiveness of ionization that airflows are considered when integrating the ionization module into the HVAC system. Analyses with computational fluid dynamics (CFD) are used to ensure that the incidence of transverse flows and backflows between electrodes are kept to an absolute minimum. This is the only way to safeguard the formation and delivery of HO2- ions in quantities sufficient to effectively “deactivate” microorganisms in the air.

FRAGRANCING

A study conducted by the German market research institute Gesellschaft für Konsumforschung (GfK), probing the market potential for integrated fragrancing systems for passenger car and truck interiors, concluded the following:

In the subcompact and compact segment, 75% of the participating passenger car drivers/owners surveyed considered a fragrancing system (a Behr prototype was presented) to be an interesting or highly interesting product. The total surveyed (Germany) was n = 400. In the mid-range segment, this rose to 83%, rising again in the premium segment even as much as 87%. Approximately 60% of those surveyed reported to be already using one of the many popular scented air freshening attachments/air freshener trees. For the truck drivers the total surveyed (Europe) was n = 300. More than 80% of truck drivers questioned similarly indicated an interest in fragrancing systems.

FRAGRANCING SYSTEM CRITERIA

In recognition of this high interest, as well as in attempts to further customize and enhance passenger comfort, the first automotive manufacturers have begun to offer fragrancing systems in their vehicles as standard and optional equipment. An integrated fragrancing system must adhere to the following principles, also supported by market research:

- A sufficient number of fragrances to suite individual preferences must be available; occupants must have the option to choose between them.
- The system must not pose any health hazard, and must be suitable for people with allergies.
- The fragrance intensity must be adjustable.
- Fragrance diffusion must be regulated to ensure occupants do not become accustomed to the fragrance and then no longer notice it.
- Operation must be user-friendly, and cartridges must be quick and easy to replace.
- Fragrancing system and operation must be styled to reflect the high quality of the vehicle.

Behr’s own fragrance diffuser, the first fully integrated system with an autonomously operating air supply, meets all of the above requirements.

Preferences and compatibility: There are currently various fragrances and fragrance intensities available to customize the scenting experience. New compositions are also being developed as automotive manufacturers and perfume manufacturers join forces. All substances used in fragrances comply with relevant health
and environmental protection regulations. If required by the customer, allergenic substances can be excluded or explicitly identified on the packaging. Only harmless substances that have been appropriately tested and approved for commercial sale are used.

Fragrance intensity and accustomization: Everyone experiences scents differently, according to personal emotive associations and memories. The ability to manually adjust the fragrance intensity in three stages caters to these personal differences. Interval-based operation prevents accustomizing to the scent. The consequence of accustomization is a decreased and later entirely diminished awareness of the fragrance. The olfactory mucous membranes in the nose become fatigued with the prolonged onset of the fragrance.

If an individual remains in a scented environment for extended periods, the degree of awareness of the particular fragrance is lost. The ability to detect other odors remains, however. The Behr module therefore provides a controllable pulse mode with intervals, to prevent diminished awareness and prolong the service life of the fragrance cartridges. The system's basic module has not to be modified.

FUNCTIONING OF THE FRAGRANCE DIFFUSER MODULE

The air to be scented is drawn from the conditioned vehicle cabin using an integrated blower in the fragrance diffuser module. Air ventilation doors direct the flow of air across the fragrance cartridges and back into the vehicle interior. The fragrance intensity corresponds to the degree at which the air is enriched with fragrance molecules. The fragrance diffuser is controlled by an independent control head that receives all necessary parameters regarding climate control settings from the air conditioning control unit.

These parameters include air temperature and air distribution in the cabin (ventilation level, footwell), operating mode (external or recirculated air mode), and airflow through the cabin. The following can also be considered: the duration of use of the fragrance diffuser (high fragrance intensity for short journeys, low intensity for longer journeys) and the intensity of the fragrance used. Based on this information, a preset algorithm is used to calculate the pulse amplitude, pulse duration, and interval time. It is therefore possible to regulate the airflow across the fragrance cartridges in the module to ensure the preselected intensity remains the same, even though vehicle and cabin parameters are changed.

FRAGRANCING VALIDATION

The selection and validation of the fragrance precede the validation of the module. If the fragrance's acceptance, stability, and lifespan are verified, the module is validated. Two factors are particularly important in this regard:

- a consistent fragrance intensity, despite modification of air conditioning system settings

\[\text{Diagram}\] Layout of fragrance diffuser module from Behr
material compatibility of fragrance substances and module materials, and, if necessary, peripheral module equipment such as air ducts and vents in the dashboard. Olfactometric analyses have proven inadequate with regard to evaluating the consistency of fragrance intensity. Behr specialists have therefore developed a procedure to facilitate precise quantification of scent molecules in the vehicle interior using a gas chromatograph and/or flame ionization detector (FID). Since perfumes are highly complex mixtures, sometimes comprising over 100 separate components, the process uses test fragrances as model mixtures. These consist of non-volatile, medium and high boiling components. Their “fingerprints” are recorded in the analysis. These model mixtures enable the derived quantities to be tracked. The degree of airflow scenting lies in the lower ppm range, depending on the door opening angle and duration. The objective is to keep the degree of fragrancing within the detection threshold of the vehicle occupants at all times, since only in this way can a pleasant scent experience be maintained over extended periods.

Behr also has expertise with respect to the determination of material compatibility. This concerns the selection of materials and components for the fragrance diffuser module, air ducts, and outlets. Necessary materials testing of surrounding components is highly coordinated, involving automotive manufacturers, fragrance manufacturers, and manufacturers of components that come into contact with fragrance substances (including essential oils and solvents), both inside and outside the fragrance diffuser. This means that the vehicle in which the diffuser is installed must also be included in the validation process.

SUMMARY

The holistic approach by Behr is essential for the generation of high customer benefit. Therefore, the supplier uses a bottom-up approach with so-called air quality steps. To do so requires each step of the air quality – filtration, sensor technology, surface treatment as BehrOxal and biocide coating as BehrOxal nano, ionization, and fragrancing – to be customized to the vehicle. With this air quality system, future customer requirements can be better addressed and greater comfort brought to the vehicle interior as an environment and workplace.

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