EXPERIMENTAL INVESTIGATION OF NITROGEN DIOXIDES ADSORPTION FROM CABIN AIR BY ACTIVATED CHARCOAL AIR FILTERS

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Abstract

The popularity of combination filters of cabin air has increased considerably in last decade. The main goal of such filters is to eliminate particles and gaseous pollutants from the cabin air. The removal of the noxious gases takes place by adsorption in a layer of activated charcoal granules. According to international standards these cabin air filters are tested at a temperature of 23 °C and 50 % relative humidity. But in practice they are exposed to temperatures, humidities and input concentrations varying over a wide range. Due to the strong effect of these parameters on adsorption, the adsorption capacity of cabin air filters are affected significantly. Experiments were performed at the filter test rig of the Department of Mechanical Engineering at the University of Duisburg with varying temperature, relative humidity and input concentrations. The experiments have shown that adsorption capacity is reduced significantly at higher temperatures and higher relative humidities. Additionally a further increase in temperature and the relative humidity results in an inversion of the process, namely desorption of previously adsorbed pollutants.

Keywords: *Cabin Air filters; Activated Charcoal; Nitrogen Dioxides Adsorption; Noxious Gases*

Introduction

Since year 1995 cabin air filters for cars are available which eliminate particles and gaseous pollutants from the air entering the car through the ventilation system (see figure 1). For reapers or tractors these cabin air filters have been used earlier. Cabin air filters are normally tied to air conditioning. Due to the rising popularity of air conditioning systems in small and midrange cars, usage of cabin air filters for cars has been increasing in recent years. The removal of the noxious gases takes place by adsorption using activated charcoal as adsorbent. Today cabin air filters are called as combination filters in many cases meaning that the elimination of particles and gaseous pollutants takes place in one filter. Usually granules of activated charcoal are fixed between supporting layers composed of fibers (see figure 1). These supporting layers have the additional effect of filtering particles. The layer of activated charcoal is only a few millimeters thick resulting in a characteristic adsorption behavior. This study works on the dynamic capacity of cabin air filters concerning adsorption. In Germany cabin air filters are tested according to DIN 71460 (draft status [1]). The aim of this standard as well as of the American and the International counterpart is to fix a testing procedure to make cabin air filters comparable. The testing consists of measuring the breakthrough curves of several representative gases at one specific air condition (23 °C and 50 % relative humidity). But the results of the tests gives no information about the adsorption capacity under changing surrounding conditions (temperature and relative humidity) and input concentrations [2,3] nor do they consider aging phenomenon during lifetime. Since adsorption is strongly dependent on the surrounding conditions, which are changing continuously, it is necessary to investigate the dynamic behavior of cabin air filters to characterize them [4, 5]. The results of the investigation should be used to improve the performance of cabin air filters.

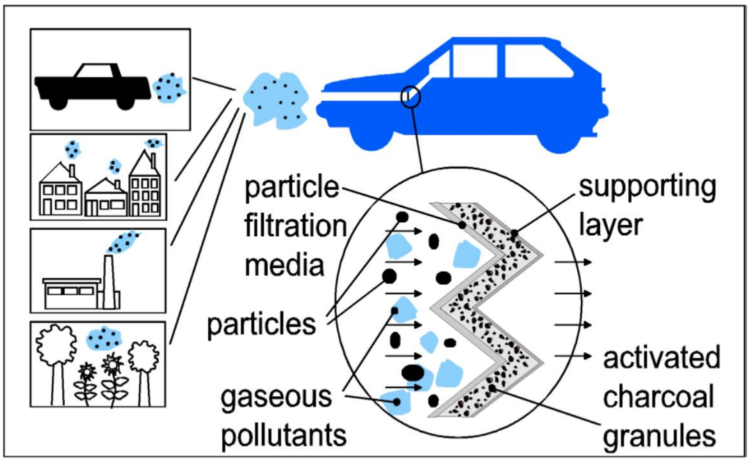

Fig. 1: Cabin air filtration

Since the cabin air filtration is relatively new technology, there is only a limited applicable space for installation. Therefore the active filter surface is relatively small, though there have been attempts to enlarge it by pleating. The resulting velocities are up to 0.44 m/s. The filters are so thin that gases remain in the filter just for a few milliseconds. This period of time is extremely short and no mass transfer zone can be developed under these conditions. Hence mass transfer and adsorption process does not occur in the filter. Moreover the adsorption process is strongly depending on temperature. This exothermic process is more efficient at lower temperatures. Capacity of adsorbents is clearly higher at low temperatures compared to the capacities attained at higher temperatures. A further increase in temperature results in an inversion of the process, namely desorption. Particularly the surrounding temperature in cabin air filtration is not stationary because cabin air filters are normally located in front of the air conditioning system [6]. While surrounding conditions in the winter time are good for adsorption, the ones in summer can reduce the capacity to zero. Another point is the dependence of adsorption on relative humidity, which is changing considerably during the operation of cabin air. Steam in the air hinders the adsorption rate of the noxious gases at least in conditions of higher relative humidity. At higher relative humidities and subsequent to adsorption of acid substances, the hydrophobic properties of the activated charcoal vanish [7, 8]. Furthermore there is a problem regarding the changing input concentrations of cabin air filters. Normally the input concentrations of adsorption processes e. g. in incinerating plants are more or less stationary. Moreover cabin air filters have to deal with dynamic concentrations depending on the surroundings of the car. Changing input concentrations may even lead to desorption when a loaded filter is rinsed with roughly pure air. The desorbed gases can't be caught again by the activated charcoal because the layers are extremely thin. In this case the filter itself will be a source of noxious gases which are not tolerable for the cabin. The changing surrounding conditions have a particularly negative effect on the dynamic behavior of adsorption in cabin air filtration and also on the capacity of the filters during their life cycle.

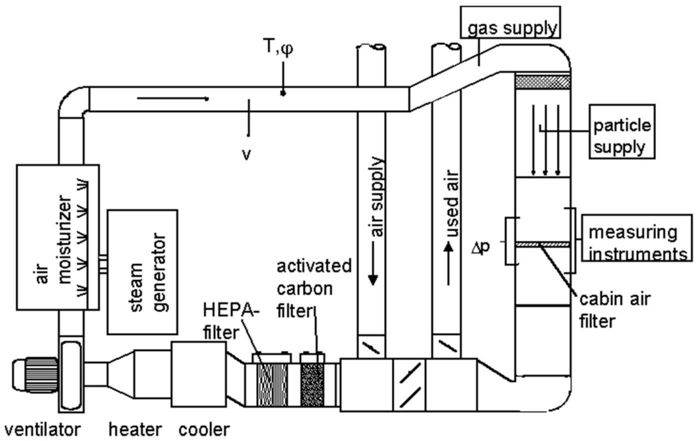

Fig. 2: Sketch of the test stand

Tests

Figure 2 shows the experimental setup build according to DIN 71460 in the filtration laboratory of the Department of Mechanical Engineering at the University of Duisburg-Germany. The investigated charcoal filters were produced by Palas GmbH, Karlsruhe-Germany. For each experiment one of these filters were installed into the experimental setup. The experimental setup can measure temperatures up to 100°C and relative humidity up to 95%. The measuring instruments used for NO2 concentration detection apply the chemiluminescence method. Adsorptive cabin air filters can not be evaluated properly regarding their real performance if they are characterized by DIN 71460 under standard conditions. For that reason breakthrough-curves are determined under various conditions, which can duplicate the real cases in a proper way. The additional equipments for air-conditioning enable the evaluation of various air conditions for cabin air filtration. As was already mentioned before, in Germany cabin air filters are tested according to DIN 71460 [1]. Though it has only draft status, it is commonly used by filter manufacturers. The aim of the described testing procedures (for filtration and adsorption) is to make cabin air filters comparable. The testing procedure for adsorption consists mainly of the measuring of breakthrough curves at 23 °C and 50 % relative humidity for the chosen substances. The concentration of nitrogen dioxide was fixed at 30 ppm in the raw gas .These concentrations are approximately 104 times higher than the actual ones known from immission measuring data [2]. These values were chosen to limit testing time and to simplify measurement techniques. The accepted emission limit in Germany is NO2 40 µg/m³ valid from 1st of January 2010. The emission limit is expected to be exceeded at locations of traffic hot spots. The theoretical modelling of the separation of nitrogen oxides is complicated because not only the adsorption but also other several reactions take place in the layer of activated carbon. Humidity of air is adsorbed in the activated carbon pores. Adsorption and formation of nitric acid may occur in these pores. In addition NO2 is catalytically reduced to NO. The separation of nitrogen oxides by activated carbon at ambient conditions has not been investigated in detail until now. At first the binary adsorption of nitrogen dioxide and water vapour in a thin layer of activated carbon was examined. An experimental setup for testing of filters according to the ISO TS 11 155-2 was used with some additional air conditioning features. Such operation parameters were chosen that cabin air filter application can be represented (15–30 °C, 30– 90 % rel. humidity, 0.2 m/s approach velocity). Concentration range of nitrogen dioxide is between 0.3 and 30 ppm.

Results

This study investigates the influence of the above mentioned factors on adsorption during the life cycle of a cabin air filter. Figure 3 shows breakthrough curves (output concentration c2 related to input concentration c1) for air with NO2 input conditions at 23°C, 50% relative humidity and 30 ppm.

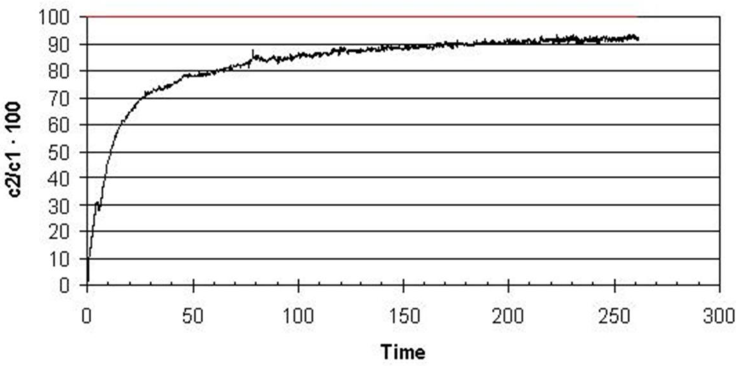

Fig. 3: Breakthrough curves of NO2 at 23°C, 50% relative humidity and 30 ppm

The experiments were performed under standard conditions mentioned above with various relative humidity. In Figure 4 the breakthrough curves of nitrogen dioxide are plotted as a function of time. After an hour the penetration or breakthrough (clean gas concentration C2 divided by the raw gas concentration C1) is higher than 20 %. The capacity of the filter is almost exhausted. With increasing humidity the lifetime of the filter is decreased to half.

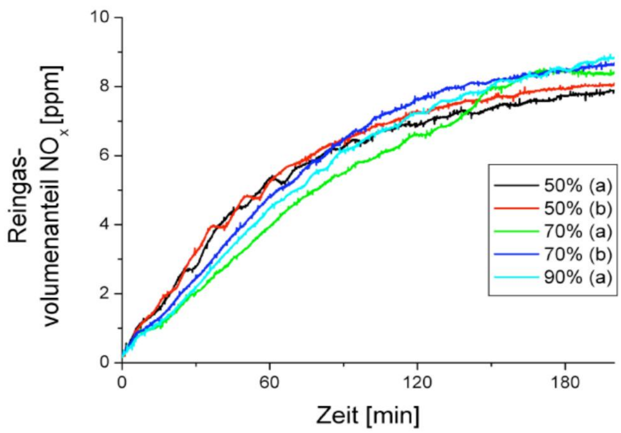

Fig. 4: Breakthrough curves of NO2 at different relative humidities

In Figure 5 the breakthrough curves of NO2 determined from the experiments are shown. In the experiments, which were performed with 50 to 90 % relative humidity, the clean gas concentration has indicated to increase rapidly to a value of about a third of the raw gas concentration. Subsequent to this sharp increase is it takes more than 90 minutes to reach 75 % of the raw gas concentration. Obviously no distinct effect of humidity was found comparing this result with those measured before. One possible explanation is that NO2 is not properly *ad*sorbed by the activated charcoal. After a running time of a few minutes the charcoal is coated with a thin layer of water and absorption of NO2 takes place in this water layer. The presented results show the importance to get temperature and relative humidity constant during the adsorption tests. This is even more important when the measurements of different test rigs are to be compared.

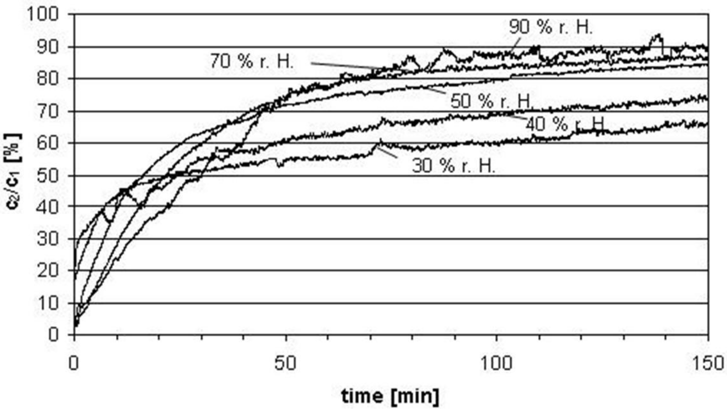

Fig. 5: The breakthrough curves of NO2 with differently relative humidity

In figure 6, N02 was fed into the raw gas so that the concentration ranges from 1 ppm up to 50 ppm (surrounding conditions: 23 °C and 50 % relative humidity). After 10 minutes of loading, the filter was rinsed with nearly clean air for 25 minutes. This case, which refers to a car ride through varying pollution areas, was repeated several times. While rinsing the filter the concentration in the clean gas was clearly higher than the one in the raw gas

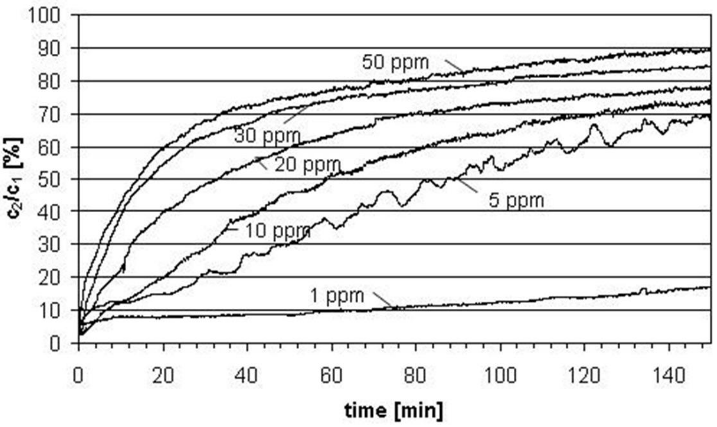

Fig. 6:. Adsorption at changing raw gas concentrations

Summary and outlook

In Germany cabin air filters are commonly tested according to DIN 71460 (draft status). The new test rig at the University of Duisburg enables tests at the standard conditions (23 °C, 50 % rel. humidity) as well as wide ranges of temperature and relative humidity. The exact adjustment of temperature and relative humidity was performed. To study the dynamic adsorption behavior of cabin air filters, ambient conditions were changed in an continuous manner or in an stepwise manner during one cycle. As expected, temperature and especially humidity indicated big influences on adsorption of NO2. The results show that further investigations at changing surrounding conditions are necessary in order to characterize cabin air filters more efficiently. They also show the necessity of an exact adjustment of temperature and relative humidity. The importance of the precise characterization of each measurement component and the flow pattern has been shown by the results of so called round robin tests. The comparability of these previous results obtained with various test rig built all in accordance with the guideline was rather bad. The results of one former test regarding filtration are given in [3]. However the comparability can be improved significantly by keeping the temperature and the relative humidity fixed during the tests.

Therefore one aim for future investigations is to cooperate with other research groups which posses filter test rigs, to compare the results of experiments and to the minimize regarding errors. Beside activated carbon also other adsorbents should be tested for a possible better adsorption behavior at changing surrounding conditions.

Additionally a mathematical model describing dynamic adsorption has to be developed, which takes the peculiarities of adsorption in thin layers into account . The principal goal in our future work is to improve cabin air filters in such a manner that they meet the actual demands.

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