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CONCEPT OF FILTER – ADSORBER TYPE INTEGRATED AIR PURIFIER†

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Abstract. *In order to prove flow-thermal and operating parameters of air purifiers in a filter-adsorber system, the authors conducted comprehensive experimental examination in the laboratory for air quality control at the Faculty of Occupational Safety in Niš. Experimental examination was carried out on original experimental equipment with the concept of integrated air purifier which includes simultaneous activity of two different filter screens on separating mechanical and chemical test contaminants from a gas mixture. For that purpose, in cooperation with several companies, we designed and produced original filter screens and provided certain conceptual solutions for purifiers. Experimental data were recorded with suitable acquisition equipment in order to identify the processes.*

Key words: *air purification, flow-thermal parameters, ventilation, data acquisition*

1. INTRODUCTION

Large systems for air purification, in most of cases, handle air pollutants in the bearing gas, which are the most prominent in given conditions. It follows that apart from this "most prominent" pollution, there are many by-pollutions of a different nature, which are not separated in the given purification technique, or are separated in a smaller quantity. The result is that, although we control air pollution, in the end we do not obtain purified air of adequate quality by certain other requirements. The investigation was started with the basic assumption that it is possible to perform air purification process by using integrated purifiers. It means that it is possible to design such air purifiers which represent a set of single mechanisms for removing impurities from the bearing gas mixture and which make a single integrated form by affecting certain pollutants and groups of pollutants.

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1.1 Concept of filter-adsorber type air purifier

For this concept of integrated purifiers, the idea is to treat different types of impurity, and for this wide array of separation mechanisms used to lead to a more effective purification process with emission levels below the upper limit. An integrated purifier like that has a number of advantages compared to a non-integrated one, and they are: higher effectiveness, small overall dimensions, low cost, low energy consumption, low manipulating costs, advantages of installation and assembly, mobility, etc.

Using single devices or systems, especially for air purification from low emission sources is uneconomic because of size, costs, and high energy loss. It means that, combining methods of removing mechanical and chemical pollutants from wasted gases with a single device, it is possible to make an integrated air purifier for universal air purification. Such concept of integrated air purifier provides better effectiveness of air purification and emission level below the upper emission level.

2. EXPERIMENTAL

2.1 Module of integrated air purifier

Module of integrated air purifier represents a compact in and out line segment of a laboratory probe line with a square cross section. It consists of a straight channel parallelepiped shape, with 600 mm in lengths, connected to two diffusers with opposite directions. Full length of the purifier module is 1270 mm. The length of the module is the result of its design, which means allowing for flow and spatial properties of the system, as well as connecting a round cross section of the channel and square cross section of the module. Sides of the module and the diffuser are made of PVC plates through mechanical treatment on a vacuum press. The result obtained is adequate compactness and strength, as well as smoothness of the inner walls of the module, important because of small hydraulic drag or occurrence of small force of friction.

Figure 1 shows the described module of integrated air purifier with the data acquisition system.

Fig. 1. Module of integrated air purifier and data acquisition system [2]

Devices for purification of mechanical and chemical pollutants, i.e. panel type filters with appropriate standard dimensions and adsorption loads shaped as a cluster group, are placed in the purifier module. With appropriate modification it is possible to load filter screens of both nonstandard dimensions and cylindrical shapes. Filters are loaded within flanges of the connective element, in other words, between front and rear module diffusers. With some modification, it is possible to set up joint activity of the rough and absolute filters (one in front of the other) and the adsorber.

2.2 Purifier of mechanical pollutants

Purifier of mechanical pollutants is an industrial panel filter, which was manufactured for experimental purposes by the well-known domestic manufacturer of filter products "Frad" from Aleksinac. It should be mentioned that this kind of filter is not part of mass production by the manufacturer but is produced according to specification by the authors of this paper in cooperation with a skilled team of the manufacturer. Internal ID numbers of used industrial panel filters are: 109.122.73/20 and 109.122.73/20A.

Although authentic, the filter has certain properties within the standard, such as dimensions and materials. Dimensions of the filter screen are 600x600 mm, and the filling is made of filter paper, manufactured by Neenah Gessner, Germany, with the following properties:

- composition of the paper: cellulose > 80%, phenol resin min. 17%
- flow: > 750 L/m^2s (with pressure drop up to 200 Pa)
- paper thickness: 0.6 mm
- specific weight: 120 g/m^2
- ripping of non-stabilised paper: > 1 bar
- ripping of stabilised paper: > 2 bar
- the biggest pore: 75 μm
- average pore: 55 μm

Figure 2 shows filter 109.122.73/20.

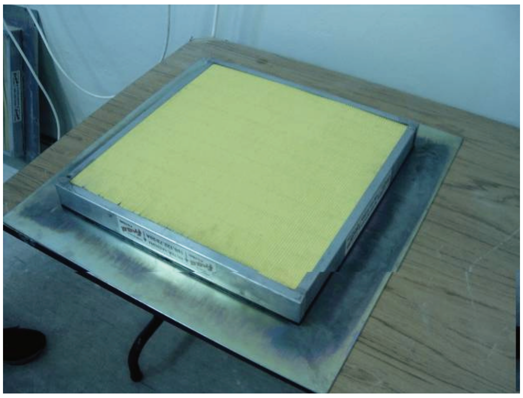

Fig. 2. Filter 109.122.73/20, view of the front, inlet side [2]

Filter of mechanical pollutants is located at the beginning of the purification module, and behind the front diffuser. It is fixed by tightening screws through a flange.

Properties of the filter element of the filter 109.122.73/20:

- filtrating area $A=6.5\ m^2$
- flow at pressure drop of $\Delta p=200$ Pa: $Q=800\ L/m^2s$
- nominal fineness of filtration: F=13.5-19 μm
- ripping point: P=2.5 bar

Filter element 109.122.73/20A is made of three pleats (sandwich) of filter paper by the same manufacturer, the first and third of which have the same function of reinforcement, with properties as in filter 109.122.73/20. The middle filter paper (fine-absolute) made on a glass fibre basis, has the following properties:

- flow at pressure drop of $\Delta p=200$ Pa: $Q > 100\ L/m^2s$
- paper thickness: 0.45 mm
- specific weight: $90\ g/m^2$
- ripping point: > 0.5 bar
- the biggest pore: 25 μm
- average pore: 18 μm

Properties of the filter element of filter 109.122.73/20A:

- filtrating area: $A=6.5\ m^2$
- flow at pressure drop of $\Delta p=200$ Pa: $Q=110\ L/m^2s$
- nominal fineness of filtration: 4-6 μm
- ripping point: P=0.5 bar

Figure 3 shows filter 109.122.73/20A.

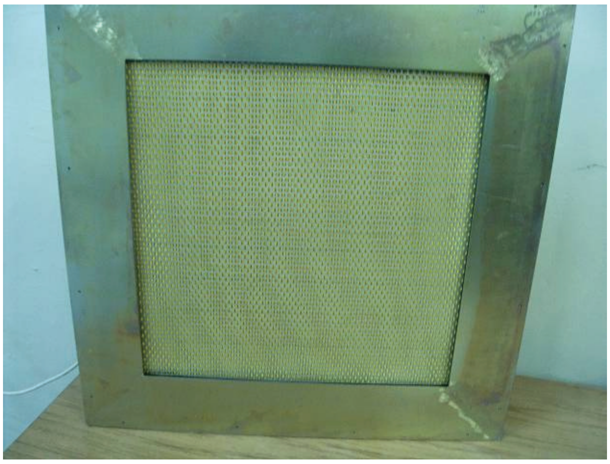

Fig. 3. Filter 109.122.73/20A, view of the rear side reinforced by perforated foil [2]

2.3 Purifier of chemical pollutants

Choice of purifier of chemical pollutants is conditioned by the nature of pollutant, specifically by whether there is a pollutant of organic or inorganic origin. Accordingly, different techniques of removing chemical pollutants are used and the paper describes the adsorption technique for removing gaseous chemical pollutants by using charcoal as the adsorber. Adsorption filling, charcoal, is packed in special cylindrical cartridges, with predefined dimensions and flow properties in order to load and adapt aerodynamic resistance during pass-through of the gas mixture.

Dimensions of the cartridge are: length $L = 500[mm]$, inner diameter $d_1 = 80[mm]$, external diameter $d_2 = 142[mm]$. The axis of the cartridge coincides with flow direction of the gas mixture thus ensuring axial inlet of gas mixture into the cartridge and then, by radial direction of flowing through the layer of adsorption loading in cartridge, its way out from the purifier module.

Figure 4 shows a single cartridge with charcoal filling, manufactured by Eko Engineering, Bor, Serbia.

Fig. 4. Cartridge with charcoal filling, Eko Engineering [2]

Radial direction of gas mixture flow is ensured by a 'blind' flange as a front area into which the gas mixture runs when entering the purifier module and by predefined perforations of inner and outer cartridge shells. Perforation size is smaller than adsorber granules – charcoal – in order to prevent leaking of the granules through cartridge perforations.

The housing of the cartridge is made by perforation of acid-resistant plastic foil, 1mm in thickness, which reduces weight and cost of the purifier and achieves resistance to chemical compounds in a gas stream. Density of the perforation is 16 holes per square centimetre but it can be modified according to charcoal granulation, flow conditions, required flow, etc.

The cartridge operates within a cluster group, usually in linear or chess arrangement. It is built into the module and as such represents the adsorption filter.

Figure 5 shows the adsorption filter in the form of a cluster group, used in experimental work.

Fig. 5. Adsorber in the purifier module in the form of a cluster group [2]

2.4 Adsorption filling of chemical pollutants purifier

In experimental work, charcoal produced by the American corporation Calgon Carbon (European branch Chemviron Carbon) with 4 mm granulation is used as adsorption filling of chemical pollutants purifier. The size of the filter is caused by necessary adsorption capacity and spatial properties of the purifier, as well as hydrodynamic and operating conditions. The filter, shown in Fig. 5, with a filling of 12 cartridges, has the following properties: Volume of one cartridge (according to given dimensions):

$$V_1 = \frac{(d_2 - d_1)^2 \pi}{4} L = 1509{,}54[cm^3] \quad (1)$$

In other words: $m_1 = 2{,}44[kg]$ of activated material.

The total volume of the filter: $V_u = 12V_1 = 18114{,}42[cm^3]$, with total mass $m_u = 12m_1 = 29{,}289[kg]$ of activated filling [1]. Activated carbon, manufactured by Calgon Carbon (USA), with name Envirocarb^{TM} AP4-60, represents pelleted charcoal with granule diameter of 4 mm, especially developed for application in purification of air and gases.

3. Results and Discussion

It should be mentioned that the whole series of pelleted charcoal by this manufacturer, named AP, is produced by high temperature activation of the coal by using steam, wherein highly porous materials with large specific area are derived. As such, they can adsorb a wide spectre of organic compounds, which makes them highly applicable in numerous technologies. This kind of charcoal has significant density that contributes to a good volume activity, which is very important if charcoal as adsorbent is used in the form of volume structures. Besides this positive property, pelleted charcoal of this series is distinguished by high mechanical strength and low content of ash (represents the part of charcoal which does not participate in the adsorption process).

A wide application range of this adsorbent is based on huge adsorption capacity for numerous organic compounds, which results in low outlet concentrations of pollutants. In addition, it shows high resistance to mechanical and thermal loading, as well as small pressure drop of charcoal layer. This directly affects the decrease in capacity (lift) of the fan, that is, the decrease in need for energy consumption. One of the properties of this adsorbent is its simple and cheap recycling, adsorption, and reuse.

Envirocarb^{TM} AP series is particularly used in the fields of: ventilation and air conditioning, treatment of volatile organic compounds (VOC), remediation of underground water, treatment of aerosols during painting and polishing process, reparation of solvents (with average boiling points, for example benzene), treatment of industrial odours, treatment of evaporation from kitchens, etc. The general specifications and specific properties of charcoal Envirocarb^{TM} AP4-60 are presented in Tables 1 and 2, respectively.

Table 1. General specifications of charcoal Envirocarb^{TM} AP4-60 [3]

		Test method
Carbon tetrachlor. activity, min. [% w/w]	60	
Density [g/ml]	0.46-0.55	TM-56 or ASTM D 2854
Butane activity [wt %]	23.3	TM-36 or ASTM D 5742
Humidity [wt%] (by weight)	up to 5	TM-1 or ASTM D 2867
Hardness, min.	90	ASTM D 3802
Grid density (US screen series)	95	> hole 8 (3.35 mm) min.
	-	< hole 6 (2.35 mm) min.

Table 2. Specific properties of charcoal EnvirocarbTM AP4-60 [3]

Bulk density [kg/m^3]	450
Loading of benzene isotherm (dry air, 20 °C, %w/w)	
288 g/m^3 (90% saturation)	39
32 g/m^3 (10% saturation)	34
3.2 g/m^3 (1% saturation)	22
0.32 g/m^3 (0.1% saturation)	13
Total area (BET method) [m^2/g]	1000
Iodine value [mg/g]	1000
Specific heat capacity on 100 °C, [kJ/kgK]	1.0
Temperature of ignition [°C] (ASTM D 3466)	410

Apart from these properties of the charcoal used, it is useful to mention recommended quantities in the adsorber/treating gas system, and those are: consumption of charcoal, time of contact, and linear velocity of gas mixture.

Consumption of charcoal represents time in which observed quantity of charcoal removes, with quality, undesired compounds from air. It is generally expressed in kg (coal)/h. Time of contact represents the rate of flow and filling volume of activated charcoal. For constant flow level, this quantity may also express the required volume of adsorbent (activated charcoal). The usual time of contact in the adsorption process is about 1 to 3 s, and it is defined by quantity of the adsorption system. Linear velocity represents conditional quantity which mostly depends on the ratio of depth (width) of the adsorption layer and its height, and it can also define the pressure drop. In fact, when applied in common gas phase, the quantity of linear velocity is about 0.1 to 0.5 m/s.

If charcoal is saturated in the adsorption process, it can be recycled by desorption and reused. This principle is called thermal reactivation and implies high temperature treatment of saturated charcoal in so called reactivation furnaces at temperatures above 800 °C. During this process, undesired organic compounds adsorbed by charcoal are destroyed, and the process is characterized by small carbon dioxide emission and high energy efficiency.

It is well known that charcoal has exceptional adsorbing properties for most organic compounds. Nevertheless, adsorption properties of charcoal can be affected by various factors, such as type of compound, concentration of the adsorbent, temperature, pressure, and humidity.

The type of compound represents its physical and chemical properties, primarily molecule weight, pressure of vapour, boiling point, refraction index, etc. For example, chemical compounds with greater molecule weight, lower pressure of vapour, higher boiling point, and larger refraction index show better adsorptive properties.

Increased concentration of the compound which is adsorbed leads to increased intensity of adsorption mechanism, i.e. to increased adsorption on the charcoal.

Temperature has a strong impact on the adsorption process, because it is in essence an exothermic process. If the adsorption mechanism on charcoal operates at lower temperature, the adsorption process intensifies or *vice versa*, if the temperature is higher, the process of adsorption decelerates.

Pressure represents another thermodynamic property of the system in which adsorption occurs. Generally higher levels of pressure positively affect the adsorption mechanism on charcoal and adsorption capacity of charcoal.

Humidity represents a property of the bearing gas (air) and it generally holds that higher levels of humidity reduce the adsorption capacity of charcoal. Conversely, the adsorption capacity of charcoal rises with the reduction in the quantity of humidity in the gas mixture.

Pelleted charcoal is also affected by its granulation. Smaller granules (3 mm) are used in cartridges with layer thickness of 10 to 50 cm. Bigger granules (4 mm and more) are used for adsorption in greater layers and have a more general purpose. In practice, this size of pellets has desirable properties of adsorption kinetics and pressure drop through the layer. In addition, pellets of the aforementioned granules are suitable for use in air purification processes.

Table 3 provides the assessment of AP4-60 pelleted charcoal capacity at temperature 20 °C, at dry air with three different concentrations.

Table 3. Assessment of capacity of pelleted charcoal AP4-60 [3]

Name	Class (TA Luft)	Mol. weight g/mol	Convers. factor (g/m^3)/ppm	Boiling point °C	Conc. of saturation g/m^3	$0,1 g/m^3$ %w/w	$1 g/m^3$ %w/w	$10 g/m^3$ %w/w
Acetone	III	56.1	0.00241	56	589	3	6	13
Benzene	IIIC	78.1	0.00326	80	319	10	18	25
Chloroform	I	119.4	0.00498	61	1014	14	23	36
Ethanol	III	46.1	0.00182	78	111	4	10	21
Hexane	III	86.2	0.00358	69	684	12	18	21
Methanol	III	32	0.00133	55	171	1	3	11
Propane	III	44.1	0.00183	−42	15110	1	2	4
Toluene	II	92.1	0.00383	110	113	21	28	35
Vinyl chlo.	IIIC	62.5	0.00280	−14	8654	2	4	8

Generally, the design of adsorption systems depends on numerous factors. However, recommendations are commonly given for parameters such as time of contact (gas and layer of adsorbent), thickness of adsorbent layer, and linear velocity (gas velocity through the layer). Recommendations for adequate use of concrete pelleted charcoal AP4-60 are the following: time of surface contact 0.5 to 5 s, thickness of adsorbent layer 0.2 to 2 m, and linear velocity 0.05 to 0.5 m/s.

Figure 6 shows isotherms of adsorption for the used pelleted charcoal AP4-60.

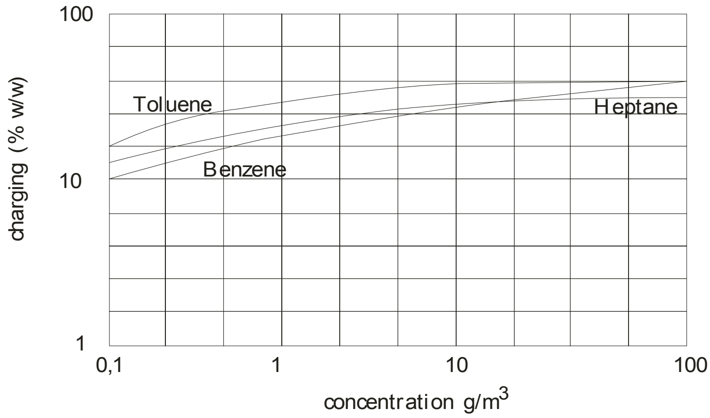

Fig. 6. Isotherms of adsorption by AP4-60 at 20 °C at dry air

Figure 7 shows a characteristic pressure drop at 20 °C, at dry air with pressure of 1013 mbar.

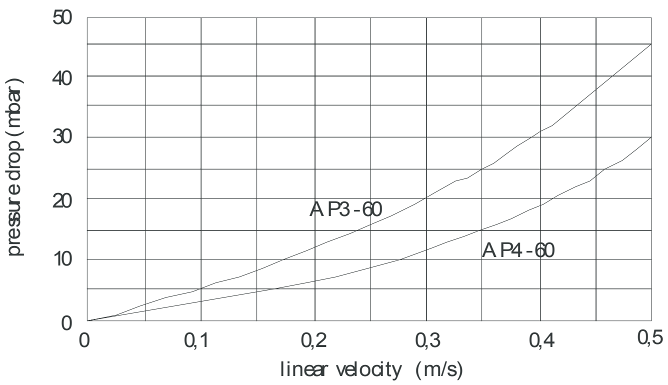

Fig. 7. Pressure drop in the function of linear velocity through the AP4-60 layer

4. CONCLUSIONS

The concept of integrated air purifier, realised in the laboratory for air quality control at the Faculty of Occupational Safety in Niš, represents a contribution to the theory and practice in the field of air environmental protection because it confirms the assumptions about the possibilities of simultaneous removal of several pollutants present in the air. Such concept of a purifier is suitable for use with low emission sources, where its advantages become truly prominent. Lower dimensions, mobility, low energy consumption, lower cost of maintenance, higher effectiveness, flexibility, etc., are only few of the advantages in comparison to single purifiers. Integrated purifiers certainly have an optimal range of conditions in which they can be used, but they can easily be adapted to specific needs of point emission sources, specific to small and medium enterprises. In general, this represents the basic advantage of integrated purifiers because all-encompassing air purification can be conducted at the source, which can significantly reduce costs and increase efficiency of environmental protection.

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KONCEPT INTEGRISANOG PREČISTAČA GASOVA TIPA FILTER – ADSORBER

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U cilju dokazivanja strujno termičkih i radnih parametara prečistača gasova u sistemu filter – adsorber, sprovedena su opsežna eksperimentalna ispitivanja u okviru laboratorije za kontrolu kvaliteta vazduha na Fakultetu zaštite na radu u Nišu. Eksperimentalna ispitivanja su izvršena na originalnoj eksperimentalnoj aparaturi sa konceptom integrisanog prečistača gasova koji podrazumeva simultano delovanje dve različite filterske pregrade na izdvajanje mehaničkih i hemijskih test zagađujućih materija iz gasne smeše. Za tu svrhu autori su, uz saradnju sa privrednim subjektima, projektovali i izradili originalne filterske pregrade i dali određena konceptualna rešenja prečistača. Eksperimentalni podaci registrovani su odgovarajućom merno akvizicionom opremom u cilju identifikacije procesa.

Ključne reči: *prečišćavanje gasova, strujno-termički parametri, ventilacija, akvizicija podataka*