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NUMERICAL STATIC ANALYSES OF AN ADSORPTION AIR FILTER CARTRIDGE PROTOTYPE

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Abstract. *The Laboratory for Air Quality Control at the Faculty of Occupational Safety in Niš in cooperation with the company Eco Engineering investigated and designed prototypes of charcoal cartridge filters in special designed PVC housing. In order to obtain comprehensive and valid investigation results, the authors carried out a number of field tests as well as numerical simulations and analyses of operating parameters and characteristics of several adsorption air purifier prototypes in an original experimental setup. The aim of this paper is to present simulation results of static (stress and strain, including thermal effect) analyses of an industrials adsorption filter prototype. The simulation and visualization of the results was done by means of a SW SimulationXpress and SW simulation design study modules from the Solid Works software package [7].*

Key words: *adsorption filter prototype, numerical simulation, static analyses*

INTRODUCTION

Nowadays, the answer to questions like whether a part will break or deform, or whether to use more or less material without affecting performance, can be obtained by different means, which can be divided in two main approaches. The first one can be described as numerous field tests of prototypes with evaluation results, which implies the modification of the part design processes until a satisfactory solution is reached.

On the other hand, simulation can help accomplish tasks such as optimizing designs by simulation concepts before making final products and reducing costs and time by testing models with a computer. This is very important if one is to maintain cheaper and more efficient production and to market products faster than the competition, and thus gain higher profits.

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Stress or static analyses calculate the displacements, strain, and stresses of a part based on material, fixtures, and loads. A different material fails when the different stress levels reach a certain level. The SW SimulationXpress module and SW Simulation design study, used in this paper, utilize linear static analyses, based on a Finite Element Method, to calculate stresses. Linear static analysis makes several assumptions to calculate stresses in a part. Those assumptions are the Linearity Assumption (the induced response is directly proportional to the applied loads); Elasticity Assumption (the part returns to its original shape if the loads are removed and it has no permanent deformation); and the Static Assumption (loads are applied slowly and gradually until they reach their full magnitudes).

The Finite Element Method (FEM) is a reliable numerical technique for analyzing engineering designs replacing a complex problem with many simple problems and dividing the model into many small pieces of simple shapes (elements).

Solid Works SimulationXpress is suitable for the stress analysis of simple parts (subassemblies), and we used it to simulate the effects of force or pressure.

The static analysis computes the effects of static loading on a model. It can display stresses, strains, displacement, and the factor of safety at each segment of the model. In the simulation, one has to specify the location and magnitude of each load, as well as to specify where and how the model is supported. Identifying where stresses are the highest/lowest quickly shows the designer where a model can be improved by adding support or by removing excess material. From the results, we can choose the optimal configuration with the required factor of safety, load conditions, or stress tolerance.

In addition to software simulation, we conducted field tests on the original experimental setup. Experimental apparatuses were constructed as a complex system of ventilation channels; the air conditioning module; filter modules for mechanical and chemical air purifiers; data acquisition; modules for the simulation of mechanical and chemical pollutants; velocity; temperature; humidity and differential pressure transmitters; the fan unit with frequent regulation, etc. The behavior of elements which share common points called nodes is well-known under all possible support and load scenarios. The motion of each node is fully described by translations in the X, Y, and Z directions, called degrees of freedom (DOFs). The analysis using FEM is called the Finite Element Analysis (FEA). The equations, formulated by the SimulationXpress, describe behavior of each element with regard to other elements, relating displacements to known material properties, fixtures, and loads. In addition, the SimulationXpress organizes the equations into a large set of simultaneous algebraic equations, and the solver calculates the displacements in the x, y, and z directions at each node, and then the stresses and strains in various directions.

Concept of the Cleaner Module for Gaseous Chemical Pollutants

The cleaner module for chemical pollutants is a compact input-output line segment of the filter-ventilation line, which includes two oppositely directed diffusers and a connecting element of the square cross-section between them. A panel was made of plastic material (PVC) by an adequate vacuum processing method, which resulted in proper compactness, strength, and smoothness of the interior walls of the modules. This is important because of the module's good mechanical resistance to vibration when the gas mixture flows through the module. The total length of the cleaner module for chemical pollutants is 1270mm. The connection between the diffusers and the body of the module is made by flanges, bolts, and nuts with a suitable sealing element in the flange.

Figure 1 provides an overview of the cleaner module for chemical impurities with the measuring and data acquisition equipment.

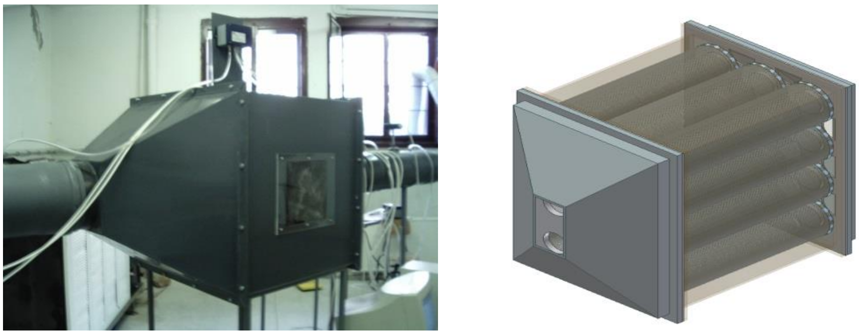


Fig. 1 The cleaner module for chemical pollutants with air ducts (fig. left), with the differential pressure transmitter on top, (fig. right, module of adsorption charcoal filter – Solid Works)

We stored adsorption filling in the form of cartridges, filled with activated carbon, in the cleaner module for chemical pollutants. The main function of the modules for treatment of chemical pollutants is to provide adequate housing and position of cartridges or activated carbon fillings, and to provide adequate flow characteristics of the gas mixture when it passes through the adsorption filling.

The cleaner for gaseous chemical pollutants

The selection of a cleaner for chemical pollutants is conditioned by the very nature of the pollutants, the conditions in which it is used, the desired degree of separation of impurities, capacity, features, ventilation system, etc.

In the experimental part of the paper, we used the adsorption filter prototype with activated carbon as a filling, which was developed in cooperation with local manufacturers of purification systems – Eco Engineering from Bor[1].

Activated carbon was placed in proper cylindrical cartridge prototypes, with a precisely defined size, adequate resistance to chemical and mechanical effects, and low aerodynamic resistance to the passage of the gas mixture through the cleaner module.

Figure 2 shows a cartridge filled with activated carbon.

Fig 2 Cartridge with activated carbon.

[1] Eco Engineering, Dr Milovanovića 4, 19210 Bor, e-mail: ekoing@yubc.net

The cartridge is cylindrical, and its axis corresponds to the flow direction of the gas mixture, which ensures an axial input of the gas mixture into the cartridge area, and then, by a radial flow direction through the adsorption filling, its output from the cleaner module for chemical impurities. Radial movement of the gas mixture through the adsorber layer is possible due to the existence of a blind panel which the gas mixture strikes when entering the cleaner module and due to the perforated inner and outer layer of the cartridge. The size of the perforation is less than the grain size of the adsorber – activated carbon, so as to avoid grains falling through the holes of cartridge layers. Dimensions of the cartridge are: length $L = 500$ [mm], inner diameter $d_1 = 80$ [mm], external diameter $d_2 = 142$ [mm].

Cartridge housing is made by the perforation of acid-resistant plastic film, 1.4 mm thick (with a variable number and size of perforations per square centimeter), thus reducing the weight and price of the filters. Perforation was performed with 9 holes per square centimeter, but can be adjusted by the particle size of activated carbon. The cartridges are in a chessboard layout and form a cluster group that is built into the adsorption filter module.

Figure 3 shows an adsorption filter in the form of a cluster group, used in the experimental part of the paper.

Fig. 3 The adsorption filter in the form of a cluster group

For the adsorption filling of the cleaner module for chemical pollutants, we used pellets of activated carbon manufactured by the Calgon Carbon Corporation from USA (European Branch – Chemviron Carbon) with different granularity (3mm, 4mm), Envirocarb^{TM} series AP4-60 AP4-60 [6].

The volume of one cartridge (according to the given dimensions) is 1509,54cm^3, or expressed through the mass of used charcoal, 2,44kg of activated material. The total volume of the filter module with 12 cartridges is 18114,42cm^3, with a total mass of 29,289kg of activated filling.

This type of activated carbon has a very high density that contributes to a fairly good volume activity, which is important if the activated carbon is used as an adsorbent in the form of volume structures. In addition to this positive feature, activated carbon pellets in this series are characterized by good mechanical strength, easy and inexpensive recycling, low ash content, resistance to thermal loads, and a low pressure drop of activated carbon in the layer. This results in the reduction of fan strain (less power). The EnvirocarbTM AP series is currently widely used in the fields of ventilation and air conditioning, treatment of volatile organic compounds (VOC), groundwater remediation, treatment of aerosols during painting and lacquering, solvent reparation (with moderate boiling points, e.g. benzene), treatment of industrial odors, treatment of kitchen fumes, and so on.

The results of the simulation -
Stress analysis of the adsorber cartridge prototype ACP-1

File Information

Model name: filter adsorber cartridge Model location: D:\adsorpber.SLDPRT
Results location: C:\Program Files\SolidWorks\COSMOS\work
Study name: Study 1 (-Default-)

1. Materials

No.	Part Name	Material	Mass	Volume
1	cover ACP-1	PVC	0.18kg	0.00151m^3

2. Load & Restraint Information

	Restraint	
Restraint-1 <poklopac ACP-1>	Round in shape, attached by glue.	
	Load	
Pressure-1 <poklopac ACP-1>	diff. pressure 2**e+005 N/m^2** along direction normal to selected face	Sequential Loading

3. Study Property

Mesh Information	
Mesh Type:	Solid mesh
Mesher Used:	Standard
Smooth Surface:	On
Jacobian Check:	4 Points
Element Size:	3.1503 mm
Tolerance:	0.11021 mm
Number of elements:	64993
Number of nodes:	138926
Time to complete mesh (hh;mm;ss)	00:24:25
Solver Information	
Solver Type:	FFEPlus
Option:	Include Thermal Effects
Thermal Option:	Input Temperature
Thermal Option:	Reference Temperature at zero strain: 298 Kelvin

4. Contact

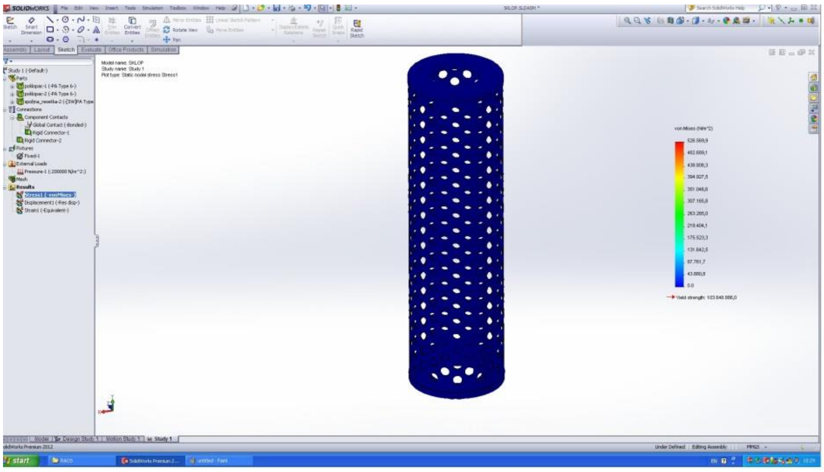
Contact state: Touching faces - Bonded

5. Results

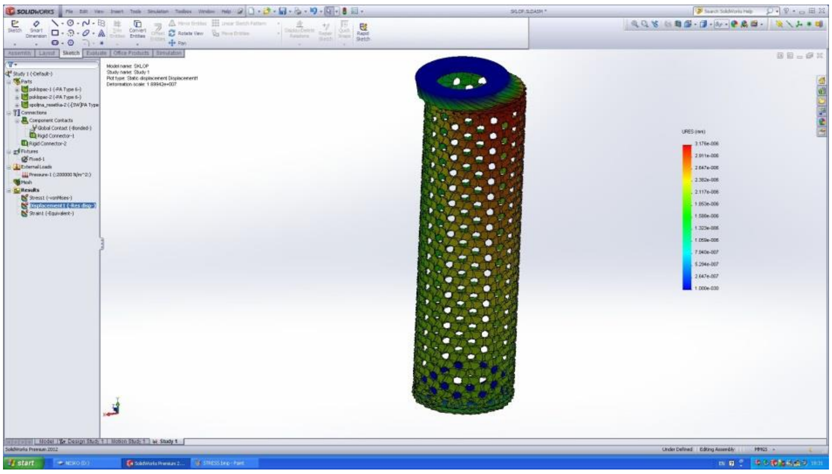
5a. Default Results

Name	Type	Min	Location	Max	Location
Stress1	VON: von Mises stress	0.002774 N/m^2 Node: 53019	(2.09501 mm, 24.2709 mm, 4.92154e-014 mm)	4.77641e+010 N/m^2 Node: 59805	(26.2291 mm, -5.10289 mm, 101.505 mm)
Displacement1	URES: Resultant displacement	0 mm Node: 1	(155.599 mm, -12.8933 mm, 200 mm)	459.324 mm Node: 88412	(66.8518 mm, 15.6942 mm, 100 mm)
Strain1	ESTRN: Equivalent strain	3.33214e-007 Element: 17912	(0.89234 mm, 9.8948 mm, 46.054 mm)	173.14 Element: 58302	(33.0361 mm, -5.10289 mm, 113.514 mm)

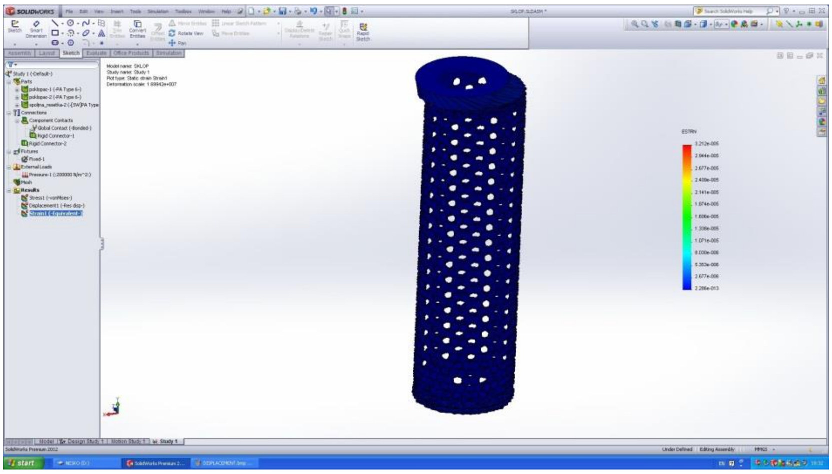
filter_paper-Study 1-Stress-Stress1



filter_paper-Study 1-Displacement-Displacement1



filter_paper-Study 1-Strain-Strain1



6. Appendix

Material name: **PVC**
Material Model Type: Linear Elastic Isotropic

Property Name	**Value**	**Units**	**Value Type**
Elastic modulus	8.96e+008	N/m^2	Constant
Poisson's ratio	0.4103	NA	Constant
Shear modulus	3.158e+008	N/m^2	Constant
Mass density	890	kg/m^3	Constant
Tensile strength	2.76e+007	N/m^2	Constant
Thermal conductivity	0.147	W/(m.K)	Constant
Specific heat	1881	J/(kg.K)	Constant

Conclusion

This paper presents a software simulation of connections and elements of an industrial prototype of an adsorption charcoal air filter. The tests related to the stress, strains, and deformation of the element's connection were conducted by use of the Solid Works software package and modules SW SimulationXpress and SW Simulation design study.

The simulation procedure set parameters for materials and connections between the elements which fully meet the criteria for the safety of structures and fracture of the cartridge construction, as well as for splitting and perforation.

Based on the results of the simulation given in graphs of the stress, strain and displacement of the studied elements, which show the quantification of the corresponding size by the color spectrum, we determined the critical locations.

On the basis of these results and the high safety level, simulations show the possibility of the optimization of components and assemblies in terms of choice of different materials, dimensions, shapes and number of perforations in order to reduce production costs and at the same time maintain optimal flow conditions, with a low pressure drop and highest separation of gaseous pollutants.

REFERENCES

1. M. Raos, Lj. Živković, N. Živković, B. Todorović, *Modelling of air pollution control devices using neural networks,* Facta Universitatis, Series: Working and Living Environmental Protection, VOL. 2, No 5, Niš, 2005, 485-492.
2. M. Raos, *Investigation of integrated air purifier from low power emission sources*, Ph. D. Thesis, University of Niš, Faculty of Occupational Safety, 2008.
3. Raos M., Živković Lj., Đorđević A., B. Todorović, *Modelling of the filter-adsorber type air cleaner by using Neural Network,* Scientific Journal Facta Universitatis, Series: Physics, Chemistry and Technology Vol. 7, No 1, 2009, pp. 23 – 31, DOI: 10.2298/FUPCT0901023R.
4. Raos M., Živković Lj., Đorđević A., N. Živković, J. Radosavljević, *Concept of the filter-adsorbet type integrtated air purifier,* Scientific Journal Facta Universitatis, Series: Physics, Chemistry and Technology Vol. 8, No 1, 2010, pp. 57 – 66, DOI: 10.2298/FUPCT1001057R.
5. Raos M., Živković, Lj.; Todorović, B, Živković, N.; Đorđević, A., Radosavljević, J., M*odelling of parameters of the air purifzing process with a filter-adsorber type purifier by use of neural network,* Scientific Journal Strojarstvo, Vol. 53, No. 3, 2011, pp 165-170, ISSN 0562-1887.
6. Envirocarb^{TM} , *Adsorption capacity, Chemviron Carbon, Application & Service Bulletin*, European operations of Calgon Carbon Corporation, Belgium, 2004., Calgon Carbon, Pittsburg, PA, USA, 2004.
7. SolidWorks 2007, SPO.0, Software [6].

NUMERIČKA STATIČKA ANALIZA PATRONE PROTOTIPA ADSORPCIONOG FILTERA VAZDUHA

Laboratorija za upravljanje kvalitetom vazduha na Fakultetu zaštite na radu u Nišu u saradnji sa preduzećem Eco Engineering ispitivala je i izradila nekoliko prototipova adsorpcionih filtara sa aktivnim ugljem smeštenim u posebno projektovanom PVC kućištu. U cilju dobijanja sveobuhvatnih i validnih rezultata istraživanja autori su sproveli brojna eksperimentalna istraživanja kao i numeričke simulacije i analize radnih parametera i karakterisitika nekoliko prototipova adsorpcionih prečistača prečistača vazduha na originalnoj eksperimentalnoj aparaturi. Suština ovog rada je da prezentuje rezultate numeričkih simulacija opterećenja i statičke analize prototipa kućišta industrijskog adsorpcionog filtera vazduha. Simulacija i prikaz rezultata rada urađeni su korišćenjem SW modula SimulationXpress i SW Simulation design study u softwerskom paketu Solid Works.

Ključne reči: *prototip adsorpcionog filtra, numerička simulacija, statička analiza*