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ESPVI 4.0W: A USEFUL SIMULATION AND EDUCATIONAL SOFTWARE FOR PLATE-TYPE ELECTROSTATIC PRECIPITATORS

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ABSTRACT: Control of dust emissions from industrial processes (power plants, steel industries, cement industries, etc.) must be done to protect the environment and human health. Plate-type electrostatic precipitators are the main equipment used in depollution of large gas flows with dust. The article presents software for operation of industrial plate-type electrostatic precipitators, depending on the geometrical, electrical, and technological parameters. This software can be successfully used in simulation and educational purposes, to evaluate the performance of plate-type electrostatic precipitators in different operating conditions. ESPVI 4.0.A allows simulations of ESPs in various modes of operation and under various constructive solutions.

Keywords: plate-type electrostatic precipitator, pollution, simulation

1. INTRODUCTION

To depollution of high gas flow rates can be use plate-type electrostatic precipitators (ESPs). People working with ESPs must understand their functioning, to identify and resolve faults that occur in operation, and seek ways to improve performance ^[1-3]. Over the years, were made mathematical models of physical phenomena occurring at ESPs' operation ^[4]. On the market are performance software solutions to modeling ESPs' operation ^[5].

One of the most advanced mathematical models is implemented in software ESPVI 4.0W (Windows version). The model used for this software is used Deutsch equation in a complex form, taking into account the particles' diameter of the powder, the particle distribution of the dust, so that one can determine the average speed of migration depending on the particles' diameter of the powder (on diameters ranges) ^[4]. It takes into account including electrostatic charging and particles diffusion (or combination of them), on diameters ranges. Depending on the arrangement of discharge wires in sections are periodically recalculated, the charging time, and migration's speeds of dust particles. Finally, calculate the overall collection efficiency of ESP's (the most important parameter).

In the model, there is Poisson equation, which connects the electric field and charge spatial distribution. In the software can be used different geometries of the discharge wires. Depending on dust characteristics, the magnitudes and shapes of voltages from sections, and geometry and discharge wires is calculated Corona current. It is considered including back Corona effect, turbulent flow, and retraining phenomenon that occurs after shaking the dust from collecting plates and/or discharge wires. Data representation can be in SI or other measurement systems (US) ^[6,7]. Experimentation on industrial ESPs, pilot ESPs or laboratory ESPs involves financial costs, special technical problems, and long time for conducting experiments ^[4,8]. It is a very useful tool for educational and training, both for students and for people who use, every day, ESPs.

2. GEOMETRICAL, ELECTRICAL, AND TECHNOLOGICAL PARAMETERS OF ESP

In principle, the process of collecting dust particles with ESP takes place in the stages ^[4,6,8,9]:

- Production of electric field to create the Corona effect, and thus, electrical charge carriers;

- Charging dust particles by charge carriers (electrons and negative ions at negative voltage supply of ESP's sections);
- The effect of electrostatically charged dust particles in electric fields;
- Migration of dust particles in the electric field to collecting surfaces;
- Collecting of dust particles on the collecting surfaces, and then shaking the electrodes and dust particle removal (outside ESP).

ESPVI 4.0a software developed by EPA (Environmental Protection Agency - USA) in 1996 and operating under the DOS operating system has been replaced by another program ESPVI 4.0W, which basically has the same model, but it works under another operating system, Windows [6,7,10-12]. At application starting the window appears similar to that in Figure 1.

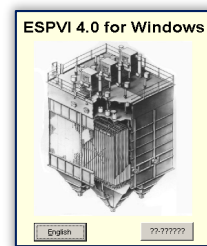


Figure 1. Window at the beginning of the application

Further, data for an ESP (geometrical, electrical, and technological parameters) are shown as an example of simulation. The menu consists of: File; Data Entry and Editing (with input of ESP's, data can be in SI or US measurement system); Calculate V-I Curve (which has several methods for calculating current-voltage characteristics of ESP's sections); Performance calculations (which has several methods for calculating the performance of ESP's); Show results (show results in text format); Graphs (show graphs of results from simulation); Help (Help menu presents for this software).

There are a number of predefined files with characteristics of industrial ESPs. There are several files Master who called SAMPLE.mst, other containing user files: ESPs' design, type and placement of discharge wires, gas and dust characteristics, magnitudes and shapes voltages from sections, etc.

From Open menu can be opened master files. In the second menu (Data entry and Editing) there are several submenus (Figs.2,3). In first position are listed the main features of ESPs and sections (Design of ESP): total specific collection surface (SCA) and specific collection surface of sections (SCA of Section), plat area and plat area of sections, gas velocity, number of sections, plate length, plate height, ESP's width, stack diameter, wire-plate spacing, dust layer depth. It can check the consistency of data (checking for linking data written).

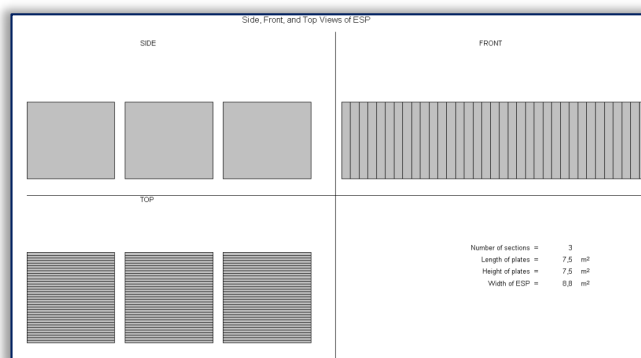


Figure 2. Window with plan upper-view of ESP

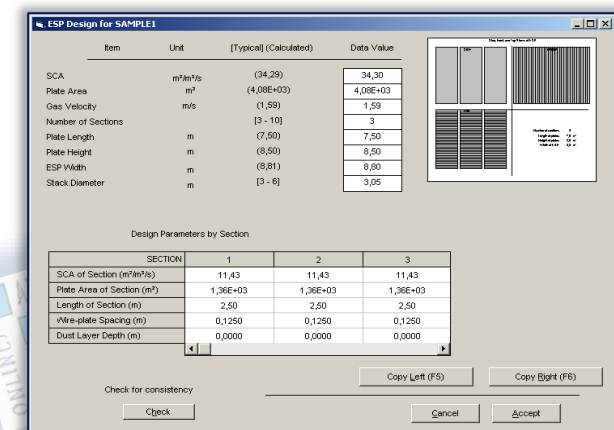


Figure 3. Window with design of ESP

The next screen (Operating voltages) from Figure 4 concerns determination of electrical parameters sections: voltage; current density; current; starting voltage; peak to average voltage ratio; maximum voltage; maximum peak voltage; maximum current; bias; wave form number; dust resistivity.

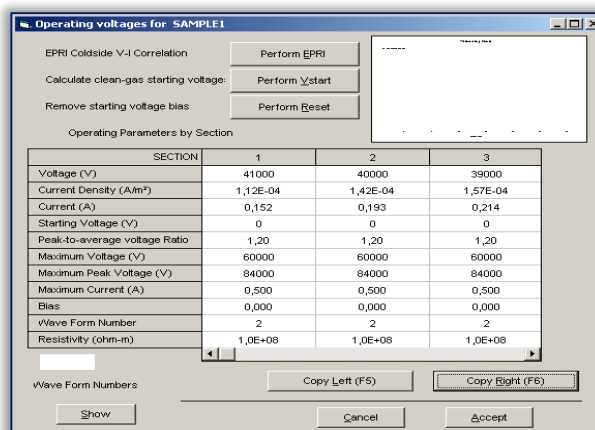


Figure 4. Window with operating voltages

Correlation can be made for current-voltage characteristics of the sections and can be calculated Corona on set voltages for section separately.

The window showing the design of discharge wires (Electrode design) is shown in Figure 5. It contains: Section number; Number of elements; Average spacing; Offset from inlet; Offset from outlet; Type; Element diameter; Location from inlet; Corona onset factor.

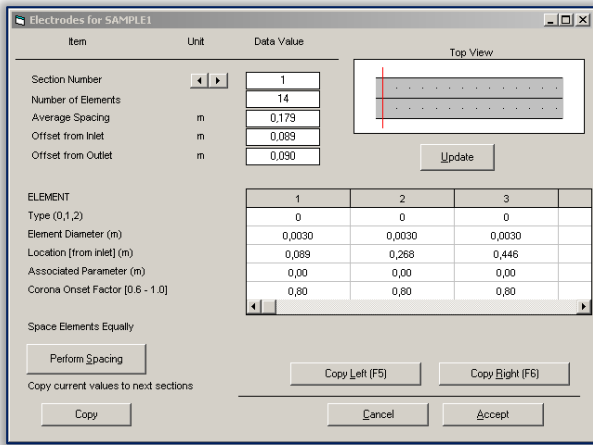


Figure 5. Window with discharge wires design

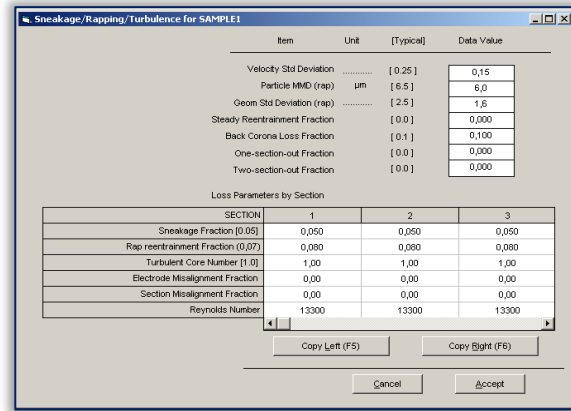


Figure 6. Window with sneakage/rapping/turbulence

The next window (Figure 6) relates to the flow of gas, to the electrodes shaking (sneakage/rapping/ turbulence); Velocity std. deviation; Particle MMD (mass median diameter); Geometric standard deviation; Steady retraining fraction; Back Corona fraction loss; other correction factors when using one section or two sections; Rapping retraining fraction; Turbulent core number; Electrodes misalignment fraction; Section misalignment fraction; Reynolds number.

The next window (Figure7) presents the Gas properties: Temperature; Pressure; Volumetric flow; N₂ fraction; O₂ fraction; CO₂ fraction; H₂O fraction; SO₂ fraction; SO₃ fraction; Gas viscosity; Mobility. The window with Particle properties (Figure 8) has: Mass load; Mass median diameter; Geometric standard deviation; Cumulative mass fraction; Particle properties at average diameter.

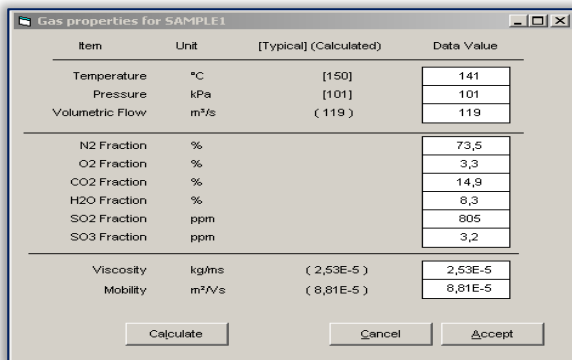


Figure7. Window with gas properties

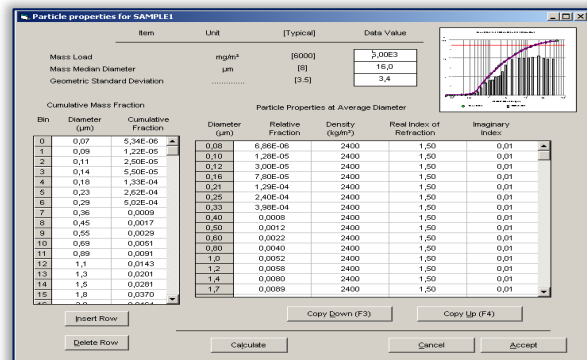


Figure 8. Window with particle properties

Can write various notes and observations for master file (extension mst). Using a menu with several windows that can be opened, and the contents of which can be modified, it improves the ability to perform simulations in various conditions.

3. SIMULATIONS RESULTS

After have entered the input data (geometric, electrical and technological parameters) of ESP, simulations can be achieved.

Another menu is calculating current-voltage characteristics (Calculate V-I Curve) which has the following sections: automatic calculation of current-voltage characteristics for each section separately (Automatic V-I Curve, eg. Current-voltage characteristic for section 1, Figure 9); calculating current-voltage characteristics for each section separately by fixed values (Fixed V-I, Figure 10); current-voltage characteristics for each discharge wires individually (Element V-I Graphical, Figure 11); options to make calculations (Calculation options, Figure 12, it can set apart the electrical parameters, the number of steps to perform iterations); Data display with operation points (Display operating points).

Another important menu is calculating the ESP performance (Performance Calc.) containing: standard method calculation (Standard method); in this submenu can be made adjustments of peak factor (Adjust peak factor), factor occurrence of Corona effect (Adjust onset factor), factor for the distribution of dust particles (Adjust particle distribution), and factor for mobility of ions (Adjust ion mobility). In this menu it can determine the distribution of various parameters from sections (Compute maldistribution).

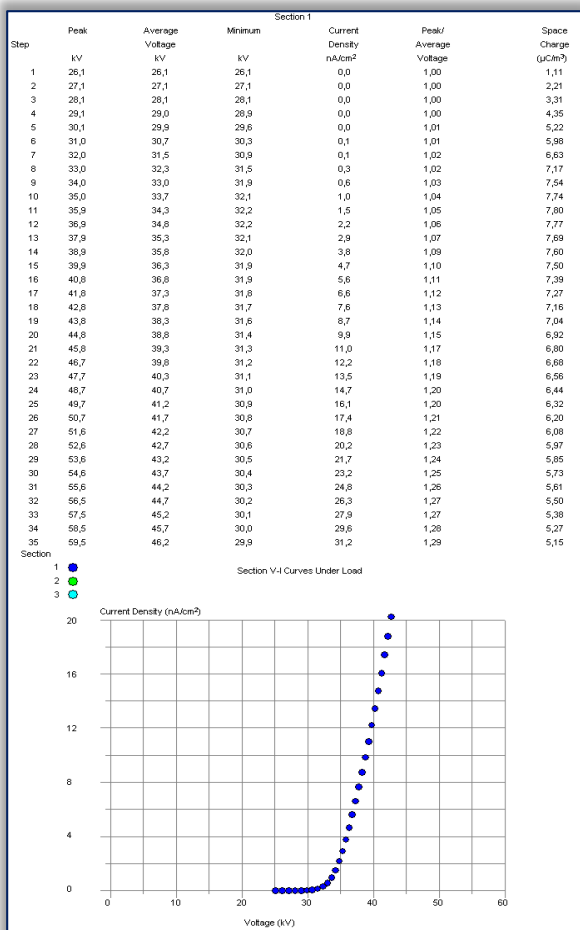


Figure 9. Automatic V-I Curves

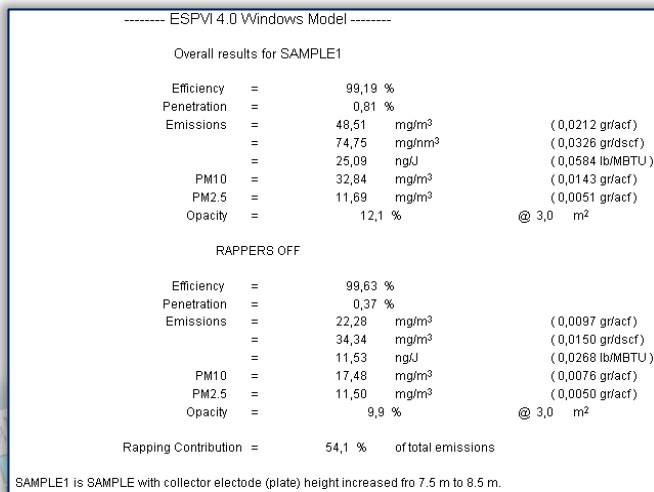


Figure13. Main results

cumulative and differential distribution of dust particles from ESP's input (Inlet particles distributions - Figure17); distribution of dust particles at the input and the output of ESP, according to the number and mass (Differential particle distributions - Figure18); waveforms voltages sections (Wave forms of voltage for sections, Figure19).

The waveform of the voltage can be half-wave rectifier voltage, full-wave rectifier voltage, and intermittent voltages with different degrees of intermittence (a pulse voltage is allowed to pass, after that a number of pulses are blocked). It can do simulations with different voltage waveforms applied differently from one section to another [2,10].

The last menu is Help menu (Help) comprising: contents of the menu (Contents), menu index (Index) and some elements about ESPVI 4.0W (about ESPVI software).

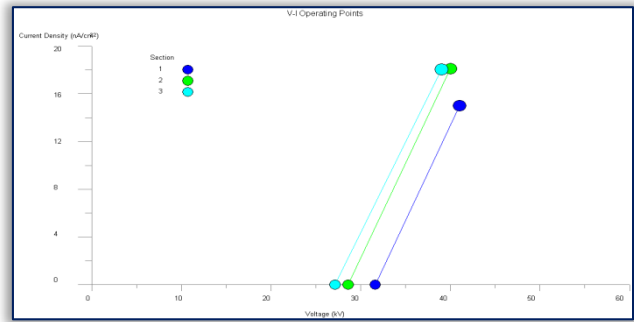


Figure10. V-I operating points

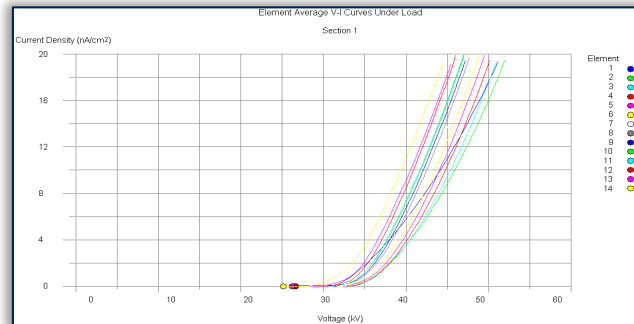


Figure 11. Element V-I Graphical

SECTION	1	2	3
Voltage (V)	53800	45200	44700
Current Density (A/m²)	3,22E-4	3,81E-4	3,95E-4
Current (A)	0,437	0,518	0,537
Starting Voltage (V)	25200	27100	26000
Peak-to-average voltage Ratio	1,115	1,328	1,342
Maximum Voltage (V)	60000	60000	60000
Maximum Peak Voltage (V)	84000	84000	84000
Maximum Current (A)	0,5	0,5	0,5
Elas	0,000	0,000	0,000
Wave Form Number	2	2	2

Figure12. Display operating points

Menu display results (Show Results) might display all calculated data (All results) or on domains (Main results - Figure13, Section parameters - Figure14, Electrodes descriptions, Non-ideal factors, Particle properties - Figure15, size-dependent penetration).

The Graphs menu contains: the plan of ESP with views (Plan View of ESPs); Electrical operating points in sections (V-I Operating points); arrangement, on the sections of the discharge wires, the emission electrodes (Electrode arrangements); distribution of dust particles penetration when shaken or when does not shaken the electrodes (Size-dependent penetration - Figure16);

Operating Parameters by Section				
Section #	SCA m ² /m ³ /s	Voltage V	Current A	Current Density A/m ²
1	11,4	53806	0,437	3,21E-04
2	11,4	45193	0,518	3,81E-04
3	11,4	44715	0,537	3,95E-04
Section #	Area m ²	Resistivity ohm-m	Wire-plate m	Thickness m
1	1360	1,00E08	0,1250	0,000
2	1360	1,00E08	0,1250	0,000
3	1360	1,00E08	0,1250	0,000
General Parameters				
Height m	8,5	Length m	7,5	Total SCA m ² /m ³ /s
				34,3
				Total Area m ²
				4080
Gas Parameters				
Volumetric Flow m ³ /s	119	Velocity m/s	1,59	Viscosity kg/m.s
				2,53E-05
				Pressure kPa
				1,01E02
Gas Analysis				
N2 (%)	73,5	O2 (%)	3,3	CO2 (%)
				14,9
				H2O (%)
				8,3
Peak/Avg ratio				
				1,12
				1,33
				1,34
Length				
				2,50
				2,50
				2,50
Wave Forms				
				Full Wave1.1
				Full Wave1.1
				Full Wave1.1
Reynolds Number				
				13300
Temperature				
				141
Mobility				
				8,81E-05
Reduced Mobility				
				5,78E-05
SO2(ppm)				
				805
SO3(ppm)				
				3,2

Figure 14. Section parameters

Particle Properties			
The 28 size band end points and cumulative fractions are:			
Particle Diameter	Fraction	Particle Diameter	Fraction
0,07	0,00001	0,36	0,00090
0,09	0,00001	0,45	0,00170
0,11	0,00002	0,55	0,00290
0,14	0,00006	0,69	0,00510
0,18	0,00013	0,89	0,00910
0,23	0,00026	1,10	0,01430
0,29	0,00050	1,30	0,02010
Inlet Number Concentration (#/m ³)			
0,08	6,40E+10	0,40	5,97E+10
0,10	6,11E+10	0,50	4,58E+10
0,12	8,29E+10	0,60	4,96E+10
0,16	9,09E+10	0,80	3,73E+10
0,21	6,65E+10	1,00	2,48E+10
0,25	7,33E+10	1,20	1,60E+10
0,33	5,29E+10	1,40	1,39E+10
General Particle Parameters			
Particle Diameter	Fraction	Particle Diameter	Fraction
1,5	0,0281	9,4	0,3315
1,8	0,0370	12,4	0,4179
2,0	0,0464	16,7	0,5146
2,4	0,0620	23,7	0,6254
3,3	0,0990	31,3	0,7692
4,9	0,1666	41,8	0,7839
6,9	0,2470	59,8	0,8592
Inlet Mass (mg/m ³)			
1,7	0,65E+09	11,0	3,10E+08
1,9	6,54E+08	14,0	1,68E+08
2,2	7,00E+08	20,0	6,61E+07
2,7	8,73E+08	28,0	1,80E+07
4,0	5,12E+09	35,0	8,42E+06
6,0	1,78E+09	50,0	2,88E+06
8,0	7,88E+08		
General Particle Parameters			
Inlet Mass	PM2.5 Inlet Mass	Density	MMD
6,00E03	1,53E02	2400	16

Figure 15. Particle properties

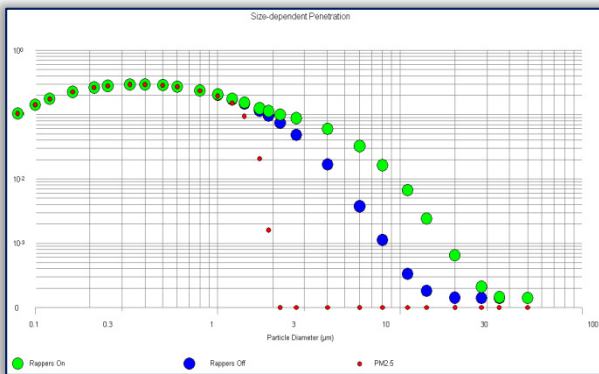


Figure 16. Size-dependent penetration

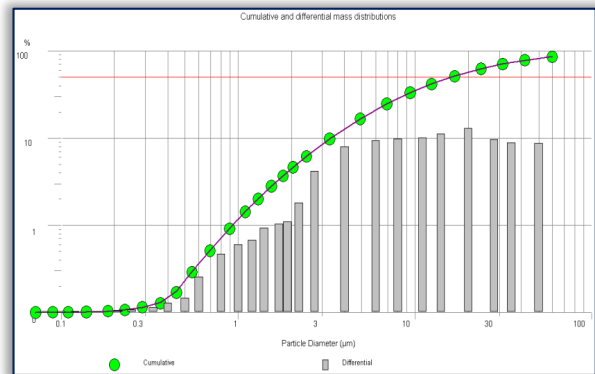


Figure 17. Inlet particles distributions

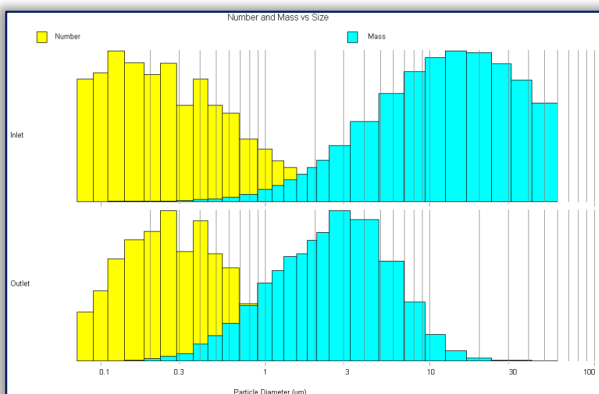


Figure 18. Differential particle distributions

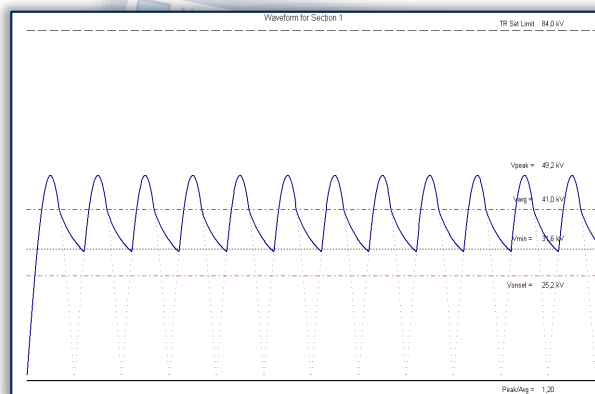


Figure 19. Full-wave rectifier voltage for sections

At the input, the largest mass of dust particles has diameters between 3-60 µm, and the greatest number of dust particles has diameters below 3 µm. At the output, the largest mass of dust particles has diameters between 1 and 10 µm, and the greatest number of dust particles has diameters of less than 1 µm.

The collection efficiency of an ESP is the most important parameter. The output concentration of dust particles with diameters below 10 μm are hundreds of mg/m^3 , and the concentration of dust particles with diameters less than 2.5 μm is tens of mg/m^3 . ESPs are huge and from that reason the collection efficiencies are high ($> 99\%$).

Experimental measurements of ESPs from industry [1-4,6,7,10] showed a great similarity between the measured and the simulated values, using ESPVI 4.0W software.

4 CONCLUSION

ESPs are the main facilities to dust depollution when treating large volumes of gas. ESPVI 4.0W software is a versatile and useful tool for evaluating the performance of industrial ESPs or those that will be implemented in the industry.

However, ESPVI 4.0W software is, also, an educational useful, both, for those who want to understand the operation, and for those who want to deepen operation of industrial ESPs.

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