



**DEVELOPING AN INTELLIGENT SOFTWARE FOR SELECTION AND DESIGN OF
AIR POLLUTION CONTROL DEVICES FOR INDUSTRIES**

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ABSTRACT

In this study, intelligent software was proposed to perform selection and design of air pollution control devices as well as pre-treatment ones. These control devices were selected among 4 groups of devices including electrostatic precipitators, bag filters, venturi scrubbers and cyclones. Regarding pre-treatment devices, the process was carried out among either cyclones or gravity settling chambers. For both air pollution control and pre-treatment devices, the process was accomplished after determining input parameters such as removal efficiency, diameter, their weight percentage and type of particle matters, pressure drop, and economic value of collected particulate matters. The most important advantage of the software developed in this study compared with others is its accurate and comprehensive design process. In addition, unlike the other software, the proposed software is capable of designing multiple devices. Finally, the developed software in this study precise design process reduces designing time and minimizes the possibility of common errors occurring in design process.

Keywords: Air pollution, Particle matter, Industrial emission, Air pollution control device, intelligent software

INTRODUCTION

As the concerns of air pollution increase, many standards have been passed by international organizations, communities and the developing countries at global and national levels. The most important of these acts are “The Clean Air Act, 1963” and its annexed (passed in 1977), New Source Performance Standards (NSPS, 1967) and National Ambient Air Quality Standards (NAAQS, 1971). While changing the production process imposes enormous costs, utilization of air pollution control devices is considered as one of the best and most effective methods used by industries. Because of high cost of design and manufacture, and also dissimilar performance of these devices in different conditions, analysis of their properties for proper selection is necessary [1]. The characteristics of gas flow (such as temperature, concentration, physical and chemical properties of particulate matter pollutant) as well as economic considerations (like economic value of collected particulate matter pollutant and economic condition of the industrial units) are among the most important parameters which are effective in design and selection of air pollution control devices [1].

In the meantime, many researches have been

done to increase the accuracy of relations and modeling procedure of gas flow carrying particular matter in the control devices [2, 3, 4, 5]. In addition, there are a few numbers of software that have been developed for designing the particulate matter pollution control devices. The most important of them which are including “Cyclone design and analysis software” developed in 1997 (to design standard cyclones), “CyDesign” and “Cyclone Design” (to design cyclones), and ESPVI 4.0W developed in 2004 (to design electrostatic precipitator under supervision of the US Environmental Protection Agency) [6]. However, the aforementioned software is incapable of designing more than one device and selecting the proper device among others. This study develops software in which the design process is performed more accurately and results are more comprehensive with comparison to the other software. In addition, using the software, selection of air pollution control devices is carried out among 4 electrostatic precipitator, bag filters, scrubbers and cyclones after determining input parameters. The selection of pre-treatment system (among gravity settling chambers and standard cyclones) is also performed by user. The effects of utilization of pre-treatment devices are considered the

design of the air pollution control device. As the other software, mentioned above, are capable of designing only one device. The multiple devices designing approach by the proposed software is significance. In this study, first, the data required for selection and design process were collected. Then the algorithms and software were developed.

Factors affecting the selection of air pollution control devices

Various parameters are being considered to select air pollution control devices. Appropriate removal efficiency, diameter, their weight percentage and type of particle matters, pressure drop, and economic value of collected particulate matters are among these parameters. These parameters are briefly described in following.

Efficiency is known as the most important parameter in selecting control devices. It is defined as the percentage decrease in particles density between inlet and outlet gas flow in control device. Generally, the performance of air pollution control devices is analyzed by considering the efficiency of collecting particle matter pollutant. The efficiency is mostly depends on diameter of the particles. The amount of particulate matters emission pollutant is usually governed by regulation codes. Gravity settling chambers and cyclones have the

lowest, and bag filters and electrostatic precipitators have the highest removal efficiency among the control devices [1, 7].

The characteristics of particulate matters are categorized as the physical and chemical properties. Size, shape and density are of the physical properties while chemical compounds, acidic or basic properties of particulate matter are of chemical properties. These characteristics play an important role in selecting air pollution control devices. For example, particles diameter is one of the most important factor; each device is capable of removing particulate matter with proper efficiency in the special range of particles diameter. Ignoring the diameter of particles and their weight percentage in selecting the control device results in problems like high pressure drop and serious decrease in efficiency (especially in specific devices like bag Filters). Chemical properties are also important in selecting the scrubbers (because of acidic wastewater formation) and bag filters (because of the textile material) [7, 8]. Concentration of particulate matters is one of the most important parameters in selecting and designing air pollution control devices. Increase in their concentration can from the dense wastewater in wet scrubbers and cause high pressure drop in bag filters [8].

Temperature and gas flow rate are also important. Increase in gas flow rate often leads to increase in inlet velocity which makes disruption in collecting particulate matters. In addition, high temperature of gas destructs the textile of bag filters.

One of the effective factors in selecting and designing air pollution control devices is the amount of pressure drop. In conditions in which the pressure drop is high, blowers will be needed to discharge the gas from the environment of the industrial facility.

In Table 1, a brief description of control devices characteristics is presented. Economic conditions and financial features are the most important factors in selecting control devices. Four parameters of capital cost, cost of operation and maintenance process, annualized cost and cost effectiveness are considered in economic analysis. The approximate cost estimation using these reported by United States Environmental Protection Agency (EPA) in 2002 is shown in Table 2. The capital cost of control devices often increase with increase in concentration rate (per unit volume) [9-13].

Design process of control devices

The control devices are designed using numeral relations which are obtained using experimental tests. As it has been mentioned, the performance of control devices is generally considered by efficiency of removing particulate matters from gas. The procedure here uses the efficiency, as it has been defined. If its value is below the appropriate level, some changes have been taken into account before the software recalculation.

Design process of gravity settling chambers

Length, width, height and efficiency of the device are the design parameters. The basis of the equations in designing of these devices is the law of universal gravitation. In these calculations, first the flow regime is determined, and then the dimensions and efficiency are calculated [14].

Design process of these devices is completely described as bellow:

1- Flow regime of the gas is determined by calculation of k:

$$k = d_p^* \left(\frac{g \rho_p \rho}{\mu^2} \right)^{\frac{1}{3}} \quad (1)$$

In which:

Table 1: The characteristics of Air Pollution Control Devices [7, 8]

Device	Diameter of particles to be removed (μm)	Proper temp. ($^{\circ} C$)	Efficiency (%)	Press. drop (cm_{h_2o})	concentration ($\frac{g}{m^3}$)	Gas flow rate ($\frac{m^3}{s}$)
Cyclones	20>	----	80	5-40	2.3-230	0.5-30
Bag Filters	----	80-300	99.9	(*)	1-23	0.1-50
Electrostatic precipitators	0.1-50	700<	99	----	1-10	0.5-50
Venturi Scrubbers	0.2<	----	95	----	1-115	0.2-478

(*) The amount of pressure drop and filter's material depends on the particle types

Table 2: Costs related to air pollution control devices (in year 2002) [9-13]

Control device	Capital Cost	O & M Cost	Annualized Cost	Cost Effectiveness
Gravity settling chambers	330-10900	13-470	40-1350	0.01-3.9
Cyclones	4600-7400	1500-18000	2800-29000	0.47-440
bag Filters	2000-180000	14000-58000	17000-106000	94-280
Electrostatic precipitators	42000-260000	8500-19000	19000-55000	47-710
Wet Scrubbers	5300-45000	9200-245000	12000-409000	77-2600

ρ_p is the density of particles and ρ is the density of gas in $\frac{g}{cm^3}$, g is the acceleration due to earth gravity in $\frac{m}{s^2}$, μ is the viscosity of gas in $\frac{g}{cm.s}$, d_p^* is the mean diameter of particles in μm .

2- In this step, relations for flow are determined:

10- If the amount of k calculated by Eq. 1 is smaller than 3, then:

(2)

In which B and L are width and length of the device in meter respectively.

And then by considering the amount of calculated BL , efficiency (E) will be determined using following equation:

$$E = \left[\frac{g\rho BL}{\rho_p} \right] d_p^2 \tag{3}$$

In which:

q is the flow rate in $\frac{m^3}{s}$.

b) If $3 < k < 43.6$, then the amount of BL is calculated by these equations:

$$BL = \left[\frac{q^{0.88} \rho^{0.254} \mu^{0.377}}{0.193(g\rho_p)^{0.623} d_p} \right]^{1.13636} \tag{4}$$

Finally, E for this regime will be determined using equation 5 as bellow:

$$E = 0.153 \frac{(g\rho_p)^{0.71} d_p^{1.14} BL}{\rho^{0.29} \mu^{0.43} q} \tag{5}$$

c) If $43.6 < k < 23404$, then BL is calculated by bellow equation:

$$BL = \left(0.33 \frac{\rho}{g\rho_p d_p} \right)^{0.5} q \tag{6}$$

And finally E for this regime will be obtained using the equation 7:

$$E = 1.74 \left[\frac{d_p g \rho_p}{\rho} \right]^{0.5} \left(\frac{BL}{q} \right) \tag{7}$$

3- In third step, BL is determined considering the amount of d_p^* using one of the equations 2, 4 or 6. In gravity settling chambers, amounts of B and L are usually the same. Therefore B and L is determined using following equation:

$$B = L = \sqrt{BL} \tag{8}$$

4- In this step the device height is calculated. For this purpose, first by considering concentration rate and using a linear interpolation, the proper inlet velocity will be calculated. The proper inlet velocity for these devices is assumed between 0.3 to

$3 \frac{m}{s}$. Finally the following equation will provide the height of the device:

$$q = VBH \rightarrow H = \frac{q}{VB} \tag{9}$$

In which V is inlet velocity of gas in $\frac{m}{s}$ and H is the height of device in meter.

5- In the last step, the efficiency of the device for any diameter will be determined using one of the equations 3, 5 or 7. The total efficiency is calculated by the following equation:

$$E_{tot} = \sum_{i=1}^5 W_i E_i \tag{10}$$

In which E_{tot} is the total efficiency, W_i is the weight percentage and E_i is the efficiency related to each diameter.

Design process of cyclones

Table 3: The proportion of device dimensions to its diameter in design of three different type of cyclone [14]

	Efficiency		
	Conventional	Medium	High
Body diameter	1	1	1
Inlet height	0.5	0.75	0.5
Inlet width	0.25	0.375	0.2
Inlet length	0.625	0.875	0.5
Inlet diameter	0.5	0.75	0.5
Cylinder length	2.5	1.5	1.5
Cone length	2	2.5	2.5

The parameters that should be calculated in designing cyclones consist of device's diameter, width and height of inlet, length and diameter of outlet, length of cylinder, pressure drop and efficiency of device [14]. Design process of these devices is completely described in following section:

Table 4: number of effective rotation for each type of cyclones

Cyclone Type	Effective rotation (N_e)
High efficiency	1.5
Conventional	3
Medium efficiency	2

3- Device's diameter is determined in third step. The equations of diameter considering

The design process of all types (high, medium and conventional efficiency) is similar. The only difference is dimension proportion which is mentioned in the table 3. The type of device and the number of effective turns should be determined in the beginning of design process. Then diameter of the device is calculated and its dimensions (height, dimensions of inlet entrance and etc.) are determined using table 3 for all the three types of cyclone. Finally, pressure drop and efficiency of the device will be calculated.

1- In first step, the type of device considering efficiency (high, conventional or medium) is determined.

2- In second step, considering the type of device and its efficiency, number of effective rotation is specified by using table 4.

device type are presented in Table 5. By using information provided by Table 3, dimensions of device will be calculated.

ρ_p is the density of particles and ρ_g is the density of gas in $\frac{g}{cm^3}$, N_e is the effective

rotation, μ is the viscosity of gas in $\frac{g}{cm.s}$, d_{p100} is the diameter of particles which are required to remove completely from the gas in μm .

Table 5: Equations for calculating the diameter of device

Cyclone Type	Device Diameter
High efficiency	$D = 10^{(\frac{8}{3})} [6.28 \frac{d_{p100}}{[\frac{9\mu}{\pi(\rho_p + \rho_g)}]^{0.5} [\frac{1}{N_e}]^{0.5}}]^{(\frac{2}{3})}$
Conventional	$D = 10^{(\frac{8}{3})} [5.568 \frac{d_{p100}}{[\frac{9\mu}{\pi(\rho_p + \rho_g)}]^{0.5} [\frac{1}{N_e}]^{0.5}}]^{(\frac{2}{3})}$
Medium efficiency	$D = 10^{(\frac{8}{3})} [1.1821 \frac{d_{p100}}{[\frac{9\mu}{\pi(\rho_p + \rho_g)}]^{0.5} [\frac{1}{N_e}]^{0.5}}]^{(\frac{2}{3})}$

4- In the last step the device efficiency is calculated using following equations (11 and 12):

$$E_i = \frac{(\frac{d}{d_{pc}})^2}{1 + (\frac{d}{d_{pc}})^2} \tag{11}$$

$$E_{tot} = \sum_{i=1}^5 W_i E_i \tag{12}$$

Design process of bag filters

In order to design the bag filter, parameters such as type of particles, fabric material, dimensions of cylinders, and the cleaning methods [8]. The first step in design process of bag filters is selection of its material based on the type of the particulate matter and the temperature of gas. On the second step, the cleaning methods of filters will be chosen based on the type of industrial activity. Third step contains selecting the amount of air to cloth ratio considering the

type of unit activity and cleaning mechanisms of filters. On the fourth step, the area of the filter's fabric is calculated. The last step will determine the total number of bags.

Design process of these devices is completely described in the following section:

- 1- In first step, the textile material is chosen based on temperature and types of pollutants (according to chemical structure of particles), presented in Table 6.
- 2- In second step, the cleaning method of filters is determined based on the activity type of unit shown in Table 7.
- 3- The amount of air to cloth ($\frac{A}{C}$) is determined based on the activity type of pollutant unit and filter cleaning method presented in Table 8.

4- In this step, the area of the fabric is calculated considering flow rate of gas (equation 13).

$$A_{tot} = \frac{Q}{A/C} \quad (13)$$

In which A_{tot} is area of fabric.

5- In fifth step, considering the cleaning method, the dimensions of device will be specified. Such dimensions are calculated using a linear interpolation determined by load and frequency of particles.

6- In this step, the total number of filters (using device area and common diameters providing by Table 8) is determined. Since the height and diameter of the available cylinders has been specified, their dimensions can be determined using discharge rate as follow:

$$N = \frac{A_{tot}}{A_c} \quad (14)$$

In which N is the total number of bags, A_c is area of each bags. Height and diameter of each cylinder is assumed 6m and 0.2m respectively.

Design process of electrostatic precipitators

Electrostatic precipitator can be found in forms of cylindrical and plate for industrial use. Designing these two types of electrostatic precipitator are similar. The most important parameters in designing

process consist of plate dimensions (length and height for planar electrostatic precipitator), diameter and height (for cylindrical electrostatic precipitator), the total number of sheets or cylinders, field's strength and applied voltage [1, 14]. In order to design these devices, first, migration velocity is determined considering the type of particulate matter. Then, the area of collecting planes will be calculated. After that, dimensions and the total number of cylinders or plates are obtained considering one loop. Finally, field's strength, applied voltage and specific collecting area (SCA) will be calculated. Design process of plate and cylindrical electrostatic precipitators is completely described in following:

a) Cylindrical electrostatic precipitators

1- First, the migration velocity (w) is determined using Table 9.

2- In second step, the area of collecting plates (A) is calculated considering the specified efficiency:

$$A = \frac{Q}{w} \ln\left(\frac{1}{1-E}\right) \quad (15)$$

In which Q is in $\frac{m^3}{s}$, w in $\frac{m}{s}$ and A in m^2 .

3- Considering one loop, height and the number of cylinders is calculated. In this loop, height is assumed 2 m at the

beginning. Then the total number of cylinders and inlet velocity is determined Using equations 16 and 17 respectively.

Table 6: typical Fabric used for bags [14]

Fabric	Flex Abrasion Resistance	Alkali Resistance	Acid Resistance	Maximum Temp.	
				discontinuous	Continuous
Cotton	Medium	Excellent	Weak	107	82
Polypropylene	Good	Excellent	Excellent	93	88
Woolen	Medium	Weak	Good	121	93
Nylon	Excellent	Excellent	Weak	121	93
Orlon	Medium	Fairly Good	Very Good	127	116
Dacron	Excellent	Fairly Good	Good	163	135
Nomex	Very Good	Fairly Good	Fairly Good	218	204
Teflon	Good	Excellent	Excellent	260	232
Fiberglass	Weak	Good	Good	288	260
Riton	Good	Excellent	Excellent	232	191

Table7: Typical industrial applications for bag filters [14]

Bag Cleaning method	Activity type of unit
shaker	Screening, crushing, and conveying of rock, products Low temperature steel applications, Metal working, Mining operations, Textiles, Woodworking processes, Chemical industry, Food industry, Coal-fired boilers
Reverse air	Cement kilns, Lime kilns, Electric steel furnaces, Ore smelters and roasters, Sintering plants, Rock dryers, Foundries, Carbon black, Magnesium oxide kilns, Coal-fired boilers
pulse jet	Pharmaceuticals, Food industry, Woodworking, Sinter plants, Metal working, Foundries, Textiles, Chemical industry, Coal-fired boilers, Asphalt batch plants, Municipal waste, incinerators

Table 8: typical air to cloth ratio

Bag Cleaning method	Air to cloth ratio ()
shaker	1-3
Reverse air	0.5-2
pulse jet	1-7.5

Table 9: The migration rate of particulate matter pollutant based on the type of particles in cm/sec [14]

Application	Particle Migration Velocity
Utility fly ash	4-20.4
Pulverized coal fly ash	10.1-13.4
Pulp and paper mills	6.4-9.5
Sulfuric acid mist	5.8-7.62
Cement (wet process)	10.1-13.3
Cement (dry process)	6.4-7
Gypsum	15.8-19.2
Smelter	1.8

If velocity is not in the range of $0.6 \frac{m}{s}$ to $2 \frac{m}{s}$, then H is increased or decreased 10 percent (based on inlet velocity) and the loop is repeated again.

$\frac{m}{s}$, then H is increased or decreased 10 percent (based on inlet velocity) and the loop is repeated again.

$$N = \frac{A}{0.628H} \tag{16}$$

$$V = \frac{Q}{0.0314N} \tag{17}$$

In which N is the number of tubes.

4- In this step, the field's strength is

calculated using the following relation:

$$E = \sqrt{\frac{12.56w\mu}{d_p}} \quad (18)$$

In which E is fields strength, μ is the viscosity of gas in $\frac{g}{cm.s}$, w is the migration velocity in $\frac{cm}{s}$.

5- Applied voltage is determined according to this equation:

$$V = E(\Delta x) = 0.2E \quad (19)$$

b) Plate electrostatic precipitators

In order to increase device's efficiency, length and width of the planes are assumed equal in design of cylindrical electrostatic precipitators.

The only difference in design of plate electrostatic precipitators compared to cylindrical ones is in third step. Regarding plate precipitators, H is set 2 m at third step. Then, the total number of planes is calculated considering total area. After that, Inlet velocity (assuming 0.2m distance between planes) is calculated. If the calculated velocity was improper, the height should be changed. The equation 21 and 22 are utilized to determine the total number of cylinders as well as the inlet velocity.

$$N = \frac{A}{H^2} \quad (21)$$

$$V = \frac{Q}{N(0.25)H} \quad (22)$$

The design process of wet scrubbers

In order to design Venturi scrubbers, throat dimensions, diameter of liquid particles, and efficiency are the most important parameters

which should be calculated. Determining these parameters requires the factors including inlet velocity, liquid to gas flow ratio, dynamic diameter of particulate matter, Reynolds number and other dimensionless quantities exist in equations should also be calculated [15]. The liquid to gas flow ratio is determined considering the amount of particulate matter loads (using a linear relation). Then, the dimensions and velocity is assumed (using a linear relation). The diameter of particulate matter and water drops will be calculated for all amounts of diameter. At next stage, k_{po} (the dimensionless inertial parameter at throat entrance), and B (dimensionless parameter characterizing the liquid-to-gas ratio) are calculated. Afterwards, penetration is calculated for different diameters. Then the efficiency will be calculated for all amounts of diameter as well as the total efficiency. All stages should be repeated if the calculated efficiency is unsuitable.

Design process of Venturi scrubbers is completely described in the following section:

1- In the first step, the amount of L/G (liquid to gas ratio) is determined considering the amount of particles load (using a linear relation):

$$\frac{L}{G} = 0.001[4.6(\frac{l_p - 1}{114})] + 0.4 \quad (23)$$

In which l_p is particles load in $\frac{g}{cm^3}$.

2- Dimensions and velocity are assumed considering gas flow rate (using a linear relation):

$$V_{gt} = 200(\frac{Q - 0.2}{27}) + 30 \quad (24)$$

In which V_{gt} is the gas velocity in $\frac{m}{s}$ and Q is the gas flow rate in $\frac{m^3}{s}$.

3- Diameter of particles and water drops (d_{pg} and d_d) are calculated using equations 25, 26 and 27 for all diameters:

$$c_c = 1 + 6.21 \times 10^{-4} (\frac{T}{d_{pg}}) \quad (25)$$

$$d_{pg} = d_{ps} (c_c \rho_p)^{0.5} \quad (26)$$

$$d_d = \frac{50}{V_{gt}} + 91.8 (\frac{L}{G})^{0.5} \quad (27)$$

In which c_c is Cunningham coefficient, and are dynamic diameter of particles, water drops and particles diameter in cm respectively. T is temperature in Kelvin.

4- At this stage, k_{po} (which is a dimensionless parameter used for calculating the amount of penetration), is calculated using equation 28 for all available diameters

$$k_{po} = \frac{d_{pg}^2 V_{gt}}{9 \mu_g d_d} \quad (28)$$

In which V_{gt} is gas velocity in $\frac{m}{s}$.

5- In this step, Reynolds number (N_{REO}), is calculated using equation 29 in which v_g is gas velocity in $\frac{cm}{s}$.

$$N_{REO} = \frac{V_{gt} d_d}{v_g} \quad (29)$$

6- In this stage, C_D is calculated using the following formula:

$$C_D = 0.22 + \frac{4}{N_{REO}} (1 + 0.15 N_{REO}^{0.6}) \quad (30)$$

7- B (which is a dimensionless parameter used for calculating the amount of permeation) is calculated considering the following equation:

$$B = (\frac{L}{G}) (\frac{\rho_l}{\rho_g C_D}) \quad (31)$$

In which ρ_l is liquid density in $\frac{g}{cm^3}$.

8- In this step, the amount of penetration P_t is determined for all available diameters using equation 32:

$$\ln(P_t(d_p)) = -B \frac{4k_{po} + 4.2 - 5.02k_{po}^2 [1 + \frac{0.7}{k_{pc}}] \tan^{-1}(\sqrt{\frac{k_{po}}{0.7}})}{k_{po} + 0.7} \quad (32)$$

9- In this point, efficiency is calculated for all available diameters as well as total efficiency. All the above stages should be repeated if the calculated efficiency is unsuitable.

(33)

10- In final stage, dimension of throat is calculated. In order to increase the efficiency, length is assumed twice the width.

Description of developed software performance

In this study, the software has been developed using Microsoft Visual Basic 6 and performs in three sections including data input, calculations and displaying output data. All required data is inputted to the software by user on the input data section. In next stage, the process of selecting and

designing of control devices is performed. Based on the input data, condition of the control devices is displayed at this point. The last section is added to display the condition of pre-treatment system based on the user; choice from either gravity settling chambers or cyclones) as well as the main control device.

Input Data

After starting the software, the "Input Data" is displayed to receive the basic parameters of design. These parameters consist of diameter of particulate matter to be totally removed, temperature in centigrade, pressure drop in centimeter of water, load of particulate matter inlet, density of particles, density and viscosity of Gas in $\frac{g}{cm^3}$, $\frac{g}{cm.s}$ and gas flow rate in $\frac{m^3}{s}$. Next, the average diameter of particles and their weight percentage is inputted in the "Particle's size data" window. Afterward, the target industry is selected as the last step in data input section.

Calculations

After entering primary data, the software displays the condition of devices based on gas characteristic, suitable configuration and the capital cost for control devices. The proposed software assumes the linear relation between the gas concentration rate and the

costs.

After selecting the type of control device, the required data should be entered into software in order to design of air pollution control device. These data for different types of devices are as follow:

- 1- Electrostatic precipitators: the migration rate of particles, dielectric constant of particles, and the type of ESP (plate or cylindrical)
- 2- Bag filters: the type of industry (with more detail than initial data section) and the type of particle matters from a chemical point of view (for determining filter fabric material)
- 3- Cyclones: g the type of desired cyclone (conventional, medium and high efficiency cyclone)
- 4- Venturi scrubbers: The density of liquid used in these devices

Also the type of pre-treatment is determined among gravity settling chambers and cyclones (conventional cyclones). The diameter of particle matters for total elimination (i.e. all particulate matter with greater diameter should be totally removed from the gas) is inputted into the software and then design of control device and pre-treatment is performed using the entered data.

Output results

The software's outputs for each control

devices are as follows:

Electrostatic precipitator: width, length and total number of plates along with distance between them (for plate Electrostatic precipitator), total number and height of cylinders (for cylindrical Electrostatic precipitator), field's strength, the SCA constant, inlet velocity, applied voltage.

Cyclones: width and length of inlet, cone and body length, device's diameter, pressure drop and efficiency.

Venturi scrubbers: length and width of throat, pressure drop, efficiency, and liquid to gas ratio.

Bag filters: total number, diameter and height of cylinders, total area of required fabric and its material type, and cleaning methods.

Gravity settling chambers: efficiency, length, width and height of device.

RESULTS AND DISCUSSIONS

In this section, the outputs resulted from running the developed software were analyzed. Examples of this section were adapted from various references such as "Air Pollution Control Equipment" [16]. In these examples, various industries such as boilers, asphalt and cement producing factories, and waste incinerators facilities were considered. Note that, gravity settling chambers were used as the pre-treatment, and cyclones, electrostatic precipitators, venturi scrubbers

and fabric filters were chosen as the control devices for particulate matter pollutant.

Example 1: Regarding an asphalt concrete plants, air pollution control devices including cyclones and venturi scrubbers, electrostatic precipitators and fabric filters were considered. The result from the developed software showed that the cyclones were the suitable control devices among others for the gas flow with characteristic given in tables 10 and 11 [16]. The results also indicated that venturi scrubbers were incapable of satisfying particles diameter, pressure drop and gas temperature. The last parameter was the reason that the fabric filters were unsuitable. The characteristics of gravity settling chambers (as pre-treatment) and designed cyclones are shown in Tables 12 and 13 respectively. The results obtained by cyclones design and analysis software were compared to result of Table 13. As it can be seen in Table 13, the developed software is capable of calculating both efficiency and device's dimensions while the other software cannot measure the efficiency. Capital cost, annualized cost, maintenance and operation cost are also shown in Table 14.

Example 2: In an incinerator the considered control devices included ESP, bag filters and scrubbers. The software developed in this study indicated that the venturi scrubber was

the suitable control device for the outlet gas flow with characteristics given in Tables 15 and 16. While other control devices were found unsuitable. The characteristics of gravity settling chamber as pre-treatment in this device are shown in Table 17. The particle diameter for a complete elimination in gravity settling chamber was assumed 60 micrometer. The properties of designed venturi scrubber are also shown in the table 18. Some of the results obtained from the software were compared to Joseph's [14] and shown in Table 18. Table 19 represents capital cost, annualized cost, maintenance and operation cost with regard to example 2. Example 3: In order to select proper control device for a boiler, ESP, bag filters, cyclones and venturi scrubbers were considered. The

gas flow of the boiler was characterized as Tables 20 and 21 [16]. The results obtained by the developed software showed that the venturi scrubbers, electrostatic precipitators and fabric filters were suitable, while cyclones were found unsuitable. Cyclones were found inappropriate because of small diameter of the particles existing in the given gas flow. In this example, only electrostatic precipitators and fabric filters were considered to design. The characteristics of gravity settling chamber employed as pre-treatment in this device are shown in Table 22. The characteristics of ESP and fabric filters are also shown in Tables 23 and 24 respectively. Table 25 shows capital cost, annualized cost, maintenance and operation cost for each device.

Table 10: Data related to gas in Problem 1

Characteristics of gas and particulate matter pollutant	Amount
Gas flow rate, $\frac{m^3}{s}$	3.69
Viscosity of gas,	0.0000123
Density of gas,	0.00121
Density of particles,	7.62
Particles diameter to be complete eliminated, μm	35
Temperature, $^{\circ}C$	350
Pressure drop (in CM_{H_2O})	8
Concentration of particles, $\frac{g}{cm^3}$	3
Efficiency (%)	80

Table 11: Particle Size Distribution Data in example 1

Average Particle Diameter, μm	Weight percentage
5	2
10	5
20	8

75	10
100	75

Table 12: The characteristics of designed gravity settling chambers in example 1

gravity settling chamber dimensions	Calculated by software
length (in m)	2.51
width (in m)	2.51
height (in m)	3.1
Efficiency (%)	54.21

Table 13: The characteristics of designed cyclone in example 1

Design parameters	Calculated by software	Calculated by cyclone design and analysis software
Body diameter	9.45	9.46
Inlet diameter	4.72	4.73
Inlet width	2.36	2.36
Diameter of gas outlet section	4.7	5.5
Device height	18.9	15.4
Height of outlet section	16.5	22.44
Length of turbulent generation section	5.67	5.29
Diameter of collected particles section	3.78	3.97
Efficiency	69.9	---

Table 14: Analysis of devices economic conditions in example 1 (in US Dollars)

Activity type	gravity settling chambers	cyclone
Capital Cost	1111	18091
O & M Cost	47	12118
Annualized Cost	136	20786

Table 15: Data related to carrier gas in example 2

Characteristics of gas and particulate matter pollutant	Amount
Gas flow rate, $\frac{m^3}{s}$	15
Viscosity of gas,	0.00002
Density of gas,	0.001
Density of particles,	1.9
Particles diameter to be complete eliminated, μm	9
Temperature, $^{\circ} C$	80
Pressure drop (in cm_{h_2o})	2
Concentration of particles, $\frac{g}{cm^3}$	1.25
Efficiency (%)	99.2

Table 16: Particle Size Distribution Data for example 2

Average Particle Diameter, μm	Weight percentage
1	15
5	25
10	20
15	20

20	20
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Table 17: The characteristics of designed gravity settling chambers in example 2

gravity settling chamber dimensions	Calculated by software
length (in m)	8.79
width (in m)	8.79
height (in m)	1.53
Efficiency (%)	4.04

Table 18: The characteristics of designed venturi scrubber in example 2

Venturi scrubber	Calculated by software	Data from Joseph, 1998
Width throat, m	0.234	---
length throat, m	0.468	---
Efficiency (%)	99.39	99.2
L/G	0.996	0.9

Table 19: Analysis of devices economic conditions in example 2 (in US Dollars)

Activity type	Gravity settling chambers	Venturi scrubber
Capital Cost	3501	97945
O & M Cost	150	247559
Annualized Cost	433	364475

Table 20: Data related to carrier gas in example 3

Characteristics of gas and particulate matter pollutant	Amount
Gas flow rate, $\frac{m^3}{s}$	8.6
Viscosity of gas,	0.00001846
Density of gas,	0.00121
Density of particles,	1.05
Particles diameter to be complete eliminated, μm	1
Temperature, $^{\circ}C$	200
Pressure drop (in cm_{h_2o})	4
Concentration of particles, $\frac{g}{cm^3}$	2
Efficiency (%)	80
Gas flow rate, $\frac{m^3}{s}$	5
Viscosity of gas,	4

Table 21: Particle Size Distribution Data for example 3

Average Particle Diameter, μm	Weight percentage
5	10
10	40
20	30
75	15

100	5
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Table 22: The characteristics of designed gravity settling chambers in example 3

gravity settling chamber dimensions	Calculated by software
length (in m)	7.022
width (in m)	7.022
height (in m)	1.65
Efficiency (%)	41

Table 23: The characteristics of tube ESP in example 3

Tube ESP dimensions	Calculated by software
Height of plate	6.6
width of plate	138
Number of plates	16.65
SCA	2.87
Inlet velocity, $\frac{m}{s}$	12507.6
Voltage, V	125076

Table 24: The characteristics of bag filter in Problem 3

Bag filter dimensions	Calculated by software
Number of tubes	23
Diameter of tubes, m	30
Height of tubes, cm	900
Area of clothes	192.4
Cleaning methods	shaker
Material	numex

Table 25: Analysis of devices economic conditions in Problem 2 (in US Dollars)

Activity type	gravity settling chambers	Bag filter	ESP
Capital Cost	2148	---	667985
O & M Cost	92	184856	234936
Annualized Cost	365	256578	214061

CONCLUSION

Air pollution control devices play an important role in controlling air quality to fulfill the standard criteria. Selecting the suitable devices by considering their limitations in various environmental and manufacturing conditions, alongside their costs imposing the industrial facilities is so essential. Monitoring the gas temperature, pressure drop, type and density of existing

pollutants in outlet gas, economic parameters (e.g. economic value of outlet pollutants) are very important to select control devices. The proper selection will result in reducing the initial costs as well as operation costs, increasing efficiency in elimination of particulate matter pollutant and extending the service life of air pollution control devices. Considering costly of launching and operating, proper selection and design of

these devices in various situations are important for each industry. This study introduced software for selection and design of air pollution control devices. The advantages of using this software are eliminating human errors as well as considering all aspects and affecting factors in selecting process (with high precision). As the various parameters and complicated relations exist in design process, the manual calculations by designers maximize computing and technical errors.

Error occurring in designing calculations leads to significant reduction in device's efficiency which consequently produces financial losses and environmental issues. So, precise designing of these devices is so important to achieve suitable efficiency. The developed software in this study precise design process reduces designing time and minimizes the possibility of common errors occurring in design process. In order to develop this software, first, required data was collected. Then, using a proper algorithm, the software has been produced. The proposed software is capable to specify the proper devices along with the issues regarding other devices (i.e. improper gas flow rate or gas temperature). This ability helps the designers to resolve these issues if needed. After selecting phase, the software designs pre-

treatment and air pollution control devices. Also, three examples were generated in which proper control devices were chosen with regard to the given characteristics of gas flow and industrial unit. The results showed precise design output compared to the other software. The important advantages of this software are its high precision and comprehensiveness (considering design capabilities of control devices) in comparison to other similar software.

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