Choice of Dust Collectors Based on Energy and Environmental Degradation in Steel Industries

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Abstract

Environmental degradation and Economic growth are two important proofs in sustainable development which are followed by steel industry. In this case, energy and environmental damages as sustainability patterns of environment have been investigated in three different dust collectors to select the most environmentally suitable dust collector for electric furnace. In this article, the consumption amount of energy and costs and environmental damages due to the Energy Consumption are determined in Venturi Scrubber (V.S), Bag Filter (B.F) and Electrostatic Precipitator (E.S.P) connected to 1 of steel in ton electrical furnaces industry by using computational methods In this way total costs in 3 mentioned dust collectors were calculated in furnace with capability of one tonnage. The results showed that the total costs of dust collectors due to energy and environmental damages in one ton furnace during one year are 152 dollars in Electrostatic Precipitator, 566 dollars in Bag Filter, and 724 dollars in Venturi Scrubber, respectively. For example in Mobarakeh iron & steel plant, EAF with 200 tonnages these numbers are 30000 - 140000 US $ per year. It can be concluded that if the steel industry is located near the rural and urban areas, the best dust collector will be Bag Filter, if the steel industry is located far from urban and rural areas, the best dust collector is Electrostatic Precipitator.

Keywords: Dust collector, Steel industry, Energy, Industrial ecology, Cost.

1. Introduction

Energy Consumption (EC) in each system contains environmental damages (ED). Therefore, promoting energy consumption efficiency should have high priority in the industrial ecosystems design [1)]. For example, effects of electricity fuel cycles on employment, government revenues and global warming are considered in a paper by Krupnick and Burtraw. They assume that marginal damages are constant with very small changes in emissions, other things equal, existing plants, which generally emit higher quantities of pollutants per kWh produced, cause greater damages than new plants [2)]. Steel industry requires the most energy amount in comparison with other industries.

Deterioration process of natural resources, fossil energies and also gas reserves have forced the scientists and researchers to take steps in order to reduce the EC [3)]. In the environmental impact assessment of the steel industries, the most impact on environment is related to air pollution resulting from Electric Arc furnace [4)]. Also, when hundreds of thousands of dust collectors installed worldwide are considered, their impacts on global warming can be noticed which is due to the EC of the dust collectors [5)]. The most important industrial dust collectors which are used to trap dusts of melting furnaces in steel industry are Venturi Scrubber (VS), Electrostatic Precipitator (ESP) and Bag Filter (BF) [6)]. ESPs separate the particles and dusts from gas flow using electrostatic forces[7)] due to their high total particle collection efficiency (99.9 %) [8)]. These devices draw the dusts and particles into the plates by applying a voltage and separate them from gas flow [9)]. Industrial applications of ESP are more in power plants, steel, gypsum and cement industries [10)]. And also one of the impacts of ESP is production of ozone gas[11-13)] and also damaging respiratory systems of humans and plants [14)]. VS dust collector is one of the most important wet collectors which works based on encounter of dust and water. The mechanism of VS can be described such that first water is entered into the convergent or throat of the Venturi by water pump and then the polluted air which contains gases, dusts and particles is also entered into the convergence part of the VS. Due to mixture of water and polluted air, dusts and gases are washed away and arrived on the diverging section of the dust collector [15)]. They have been turned to water drops and directed to the waste water part through a conductor tube [16)]. BF dust collectors are one of the main methods to prevent the discharge and release of dust in the atmosphere by using

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pulse jet method [17]. During the filtration, dusts are placed on the outer surface of filter fabric, which is caused by differential pressure of the suction fan system dusts and obstacles should be cleaned after being placed on the outer surface of the filter regularly and periodically [18]. Considering the goals of industrial ecology based on reducing EC, capital and materials, and also decreasing the ED, the need for researches to select an appropriate dust collector in steel industry (melting furnaces) seems to be necessary. Accordingly, annual consumption amount of energy and material, EDs due to these two parameters and also capital cost (considering the discount rate) are calculated for VS and Electrostatic Precipitator. It is worth mentioning that by increasing EC, the EDs also increase [19]. In the case of low resistivity dust, conventional ESP results in economically convenient with respect to Fabric Filter especially when the gas flow rate increases [20].

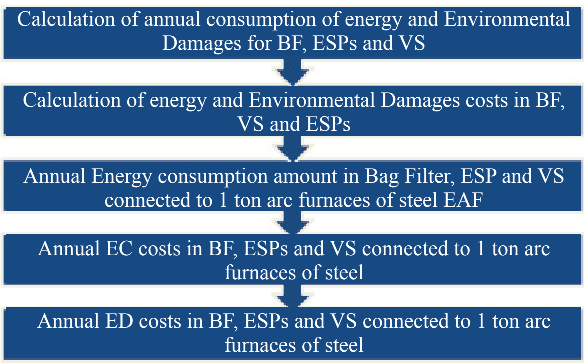
2. Materials and Methods

In this article, the consumption amount of energy and costs, ED due to the EC, are determined in VS, BF and ESP connected to 1 ton electrical arc furnaces of steel industry by using computational methods [21].

To determine the energy costs in dust collectors, EC amount is determined based on the devices that use electricity power and are connected to dust collectors, such as fans, transformers, compressor and pumps.

Then, by using the real price of electricity and annual consumption of dust collectors, annual EC cost will be calculated.

In order to determine EDs caused by EC of dust collectors, energy rate and cost of EDs are calculated. Finally the optimal dust collector can be compared and chosen by summarizing the costs, EDs and energy in dust collector working life time (Flow chart of Research method).



2.1. Calculation of annual consumption of energy and Environmental Damages for BF, ESPs and VS

The annual EC in a centrifugal fan which is connected to Electrostatic Precipitator, BF and VS is determined in Eq.1[23], after rearranging to SI unit[22].

$$FP = 0.00026\left(Q\right)\left(\Delta P\right)\left(\theta\right) \qquad \text{(Eq. 1)}$$

Where FP is fan power requirement (kw.yr^{-1}), θ is annual operating time (hr.yr^{-1}), Q is the capacity (m^3.min^{-1}) [23], and ΔP is System pressure drop (Pa) [6]. Normally the amount of pressure drop in BFs is approximately 4 to 6 inches of water gage and the amount of pressure drop in VS is estimated in Eq.2 [24], after rearranging to SI unit.

$$\Delta P = 2.450827 \times V^2 \times \rho_g \times A^{0.133} \times \left(\frac{L}{G}\right)^{0.8} \qquad \text{(Eq. 2)}$$

Where ρ_g is saturated gas stream density in Pa, V is throat velocity in meter per second (m/s), L/G is liquid to gas ratio in gallons per m^3 (gal/m^3) and, A defines the cross-sectional area of the throat in square meter (m^2). In Eq.2 which is known as Hesketh equation, the amount of liquid to gas is considered about 3 to 10 gallons per 1000 cubic feet [24]. The annual EC amount caused by compressors in BFs is determined in Eq. 3 [25].

$$\omega = \frac{1}{\eta} \times \frac{1}{\gamma - 1} P_1 Q_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{(\gamma-1)}{\gamma}} - 1\right] \qquad \text{(Eq. 3)}$$

Where ω is real power of compressor, η is efficiency of the compressor (0.5), γ is specific heat of air (1.4), P_1 is initial pressure (kPa), P_2 is final pressure (kPa), Q_1 is volumetric flow of compressor (m^3.s^{-1}).

The amount of compressed air to shake the filters is 0.5 % of fan capacity connected to dust collector, also the final pressure caused by compressor to shake the filters is about 792 (kPa) and initial pressure of one atmosphere is 101.3. The volumetric flow of the compressor is obtained by Eq. 4 [25].

$$Q_1 = Q_2 \times \frac{T_1}{T_2} \times 0.005 \qquad \text{(Eq. 4)}$$

Where Q_1 is volumetric flow of the compressor (m^3), Q_2 is volumetric flow of fan (m^3.s^{-1}) T1 is the temperature of environment (Kelvin), T_2 is the inlet temperature of BF (Kelvin) [25].

The annual EC of transformers in EPS is determined in Eq. 5 [24] after rearranging:

$$OP = 0.0208 \times A\theta \qquad \text{(Eq. 5)}$$

Where, OP is ESP operating power (kw.hr^1), A is ESP plate area (m^2), and θ is annual operating time (hr.yr^{-1}). In order to determine the area of the plates for calculating the EC of transformers and shakers in ESP, the simplest form of the equation is given below as Eq. 6 [15].

$$\eta = 1 - e^{\left(\frac{-\omega A}{Q}\right)} \qquad \text{(Eq. 6)}$$

Where η is collection efficiency of the precipitator, A is the effective collecting plate area of the precipitator (m^2), Q is gas flow through the precipitator, ($m^3.s^{-1}$), e is base of natural logarithm, ω is migration velocity ($cm.s^{-1}$) [15].

To calculate annual EC due to electromotor of the pump in VS, first the pressure drop of the pump which is a function of VS length is determined according to Eq. 7 [23], then the energy amount due to electromotor of the pump is calculated by using Eq. 8 [24]:

$$A = \frac{Q}{V} \qquad \text{(Eq. 7)}$$

Where Q is capacity rate of gas ($m^3.s^{-1}$), V is the fluid velocity in the throat ($m.s^{-1}$), A is cross section of VS throat (m^3).

$$HP_{pump} = \frac{6.1985 \times 10^{-4} \times \Delta P_{pump} \times \frac{L}{G} \times Q \times \gamma}{\eta_{pump}} \qquad \text{(Eq. 8)}$$

Where, HP pump is pump brake (kw), ηpump is efficiency of the fan (usually equal to 0.7), ΔP is pressure of the pump (mH_2O), L/G is the ratio (gallons per m^3), Q is the flow rate at inlet (cubic meter per minute) and γ is gravity of the scrubbing liquid (1.12).

2.2. Calculation of energy and Environmental Damages costs in BF, VS and ESPs

The electricity consumption cost should be multiplied into the annual EC amount (which has been mentioned in Eqs. (1), (3), (5) and (8). In Iran, industrial electricity consumption cost is 0.03 US $ per kilowatt. This number is multiplied into annual EC which has been obtained by Eqs.1, 3, 5 and 8. To determine consumed materials (water) in VS, the industrial water consumption cost which is 0.33 US $ per m^3, in Iran, has to be multiplied into annual water consumption. Considering the issue that for producing one kWh electricity , 0.0108 US $ has been determined, therefore, to determine ED due to usage of mentioned dust collectors, the electricity consumption amount caused by each dust collector is multiplied into 0.0108 US $ [19].

2.3. Annual energy consumption amount in Bag Filter, ESP and VS connected to 1 ton furnaces of steel EAF

EC amount in ESP can be investigated by calculating the EC amount in ESP fan and transformer system. According to the ACGHI standards related to VS, number 105, the capacity per each ton of steel, is 4250 $m^3.hr^{-1}$ [23], by calculating the EC amount in fan and transformer of the electrostatic system. By placing pressure drop 125 Pa velocity of the particles migration in ESPs (12.1 $cm.s^{-1}$ efficiency 99 %, annual function 2920 hours (8 hours per day) and ranges of electro motors in global market in Eqs. (1), (5) and (6) annual EC amount in ESP connected to 1 ton furnace is consequently 3471 kWh.

In order to determine the annual energy amount in VS system, it is necessary to sum the annual energy amount due to electromotor of fan and electromotor of water pump together, now considering the gas velocity in throat of Venturi (m.s-1) and using Eqs. (1), (2), (7) and (8), the annual energy amount in VS system will be 16410 kWh. Annual energy amount in Bag Filter is determined by accumulating the annual energy amount from electromotor of fan and compressor together. Therefore, by using (1), (3) and (4), the amount of annual EC in BF will be 12848 kWh.

2.4. Annual EC costs in BF, ESPs and VS connected to 1 ton furnaces of steel

Since the industrial electricity consumption cost in Iran is 0.0333 US $ per kWh, and according to the calculated annual EC in VS, BF and ESP connected to 1 furnaces EAF, the annual EC costs in ESPs are calculated as 115.76 US $ and in VS as 547 US $ and in BF as 428.2 US $.

2.5. Annual ED costs in BF, ESPs and VS connected to 1 ton furnaces of steel

Since the industrial electricity consumption costs of environmental damages (ED) in Iran are 0.0108 US $ per kWh, and according to the calculated annual ED in VS, BF and ESP connected to 1 furnaces, the annual ED costs in ESP are calculated as 37.5 US $ and in VS as 177.7 US $ and in BF as 138.7 US $.

3. Results & Discussion

The results obtained from calculations of consumption and annual energy costs in ESP and VS and BF are expressed in table1 which represent that by increasing the tonnage of the furnaces , the amount of annual energy will be increased linearly in VS, BF and ESP and also the amount is the lowest in ESP and then in VS and BF. The amount of annual energy consumption in BF is four times greater than ESP and the amount of annual energy consumption in VS is five times greater than ESP. Table 2, presents the amount of Bag Filter, VS and ESPs EC. It indicates that by increasing the tonnages of furnaces, the amount of EC will be increased linearly in dust collectors and by doubling the tonnages, the EC will be doubled and annual EC costs of BF are four times greater than ESP and the amount is five times greater in VS. In Fig. 1, shows total annual EC and ED costs in VS, ESP and BF.

Table 1. Annual EC and ED costs in VS, ESP and BF (US $).

Dust collector types	Energy consumption (US $)	Environmental damages (US $)
Venturi Scrubber (VS)	547	177.7
Electrostatic Precipitator (ESP)	115.7	37.5
Bag Filter (BF)	428.2	138.7

Table 2. EC amount in VS, ESP and BF (kWh).

Dust collector types	Energy consumption (kWh)
Venturi Scrubber (VS)	16410
Electrostatic Precipitator (ESP)	3471
Bag Filter (BF)	12848

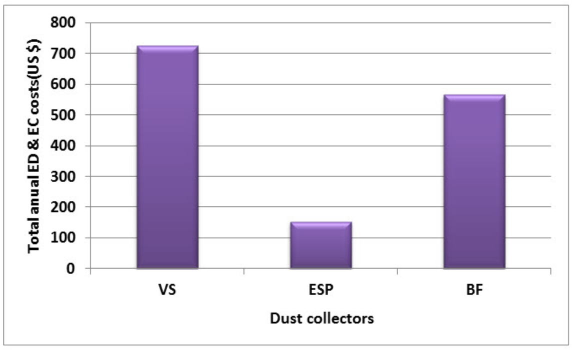


Fig.1. Total annual EC and ED costs in VS, ESP and BF.

The usage of VS and BF cause various gases including Nitrogen dioxide, Sulfur dioxide, Carbon monoxide, organic compounds and particles from power plants due to consuming high energy which cause harmful impacts on humans, plants and environment. On the other hand, the usage of ESP (Despite the low EC) due to overvoltage, produce Troposphere ozone [26].

4. Conclusion

As it has been shown, Venturi Scrubber's ED & EC costs are 177.7 & 547 US $ and Bag Filter's ED & EC costs are 138.7 & 428.2 US $ and Electrostatic Precipitator's ED & EC costs are 37.5 & 115.7 US $. Therefore, it could be concluded that VS has the highest total (EC & ED) annual cost but ESP has the lowest total (EC & ED) annual cost. It should be mentioned that BF total (EC & ED) annual cost is between ESP & VS total (EC & ED) annual cost.

Therefore, according to the results of calculations and aims of industrial ecology to reduce EC, and to reduce EDs the best option depends on the distance between the steel industry and the cities. For example in Mobarakeh Iron & Steel Plant EAF with 200 tonnages these numbers are between 30000 - 140000 US $ each year. Therefore, if the steel industry is located near the rural and urban areas, the best dust collector will be BF, if the steel industry is located far from urban and rural areas, the best dust collector is ESP because the amount of costs in BF and VS are 2.5 times greater than the ESP. They can cause environmental damages by producing ozone gas.

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