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Full Length Research Paper

Investigation of the effect of outlet pollutants of cement production industries around Tehran and approaches to control and eliminate pollutants

Siamak Boudaghpour[1]* and Alireza Jadidi[2]

[1]Department of Environmental Engineering, K. N. Toosi, University of Technology, Iran.
[2]Islamic Azad University, Tehran Jonoub, Iran.

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Air pollution is one of the most serious environmental problems in Tehran. Each day, a tremendous amount of toxic and fatal gases, different kinds of pollutants, perilous floating particles produced by cars, factories, industrial workshops, power plants and residential buildings are added to the air. Largely due to the increasing demand for cement, cement production industries around Tehran have increased their daily production. Consequently, this has led to an increase in the amount of dangerous pollutants and floating waste solid particles resulting from clinker furnaces. Suspended solid particles, carbon monoxide, carbon dioxide, different types of nitrogen oxides, sulfur oxides are the most common pollutants releasing from furnaces into atmosphere. This research is aimed at evaluating and predicting the rate of pollutants being generated in the cement production industries and discussing the approaches to eliminate and control pollutants.

Key words: Cement industry, air pollution, eliminating and controlling pollutants.

INTRODUCTION

Environment is characterized as one of the components of sustainable development at each country. Lack of attention to the environment may have unfavorable effect on the human and natural resources. From one hand, cement industries manufacturers provide the required material for development and construction and from the other hand; therefore, the environmental effects of cement industry have been the focus of a significant amount of studies around the world. And as such, some standards and criteria have been presented to control the pollutants made by cement industry. Since Iran is a developing country and is required to develop this industry, it seems necessary to investigate the environmental aspects of cement industry regarding regional climate.

Different greenhouse gases and solid particles derived from cement industries threaten air with the least supervision. As the time passes, these gases and solid particles gradually condense the environment and can be a potential risk for Tehran's atmosphere, inhabitants and animals.

The global consumption of cement is growing and reached from 2.185 billion tons in 2004 to 2.557 billion tons in 2006.

There are 46 cement factories with 69 furnaces producing 35 million tons of cement each year. The contribution of thermal energy in the cement industry is approximately 14 and 3% of consumption in the total industries and country's total consumption, respectively. Cement Industry consumes 730 million cubic meter natural gas, 2000 million liter of furnace oil and 17 million liter of oil-gas with the value of $ 293 million. In accordance with World Bank report, the estimated annual damage of loss of life and diseases due to the air pollution is about $640 and $260 million respectively.

THE SOURCE OF POLLUTANTS IN THE CEMENT FURNACE

The theory of complete combustion is applicable only in the case of ideal conditions. However, such conditions are

*Corresponding author. E-mail: bodaghpour@kntu.ac.ir.

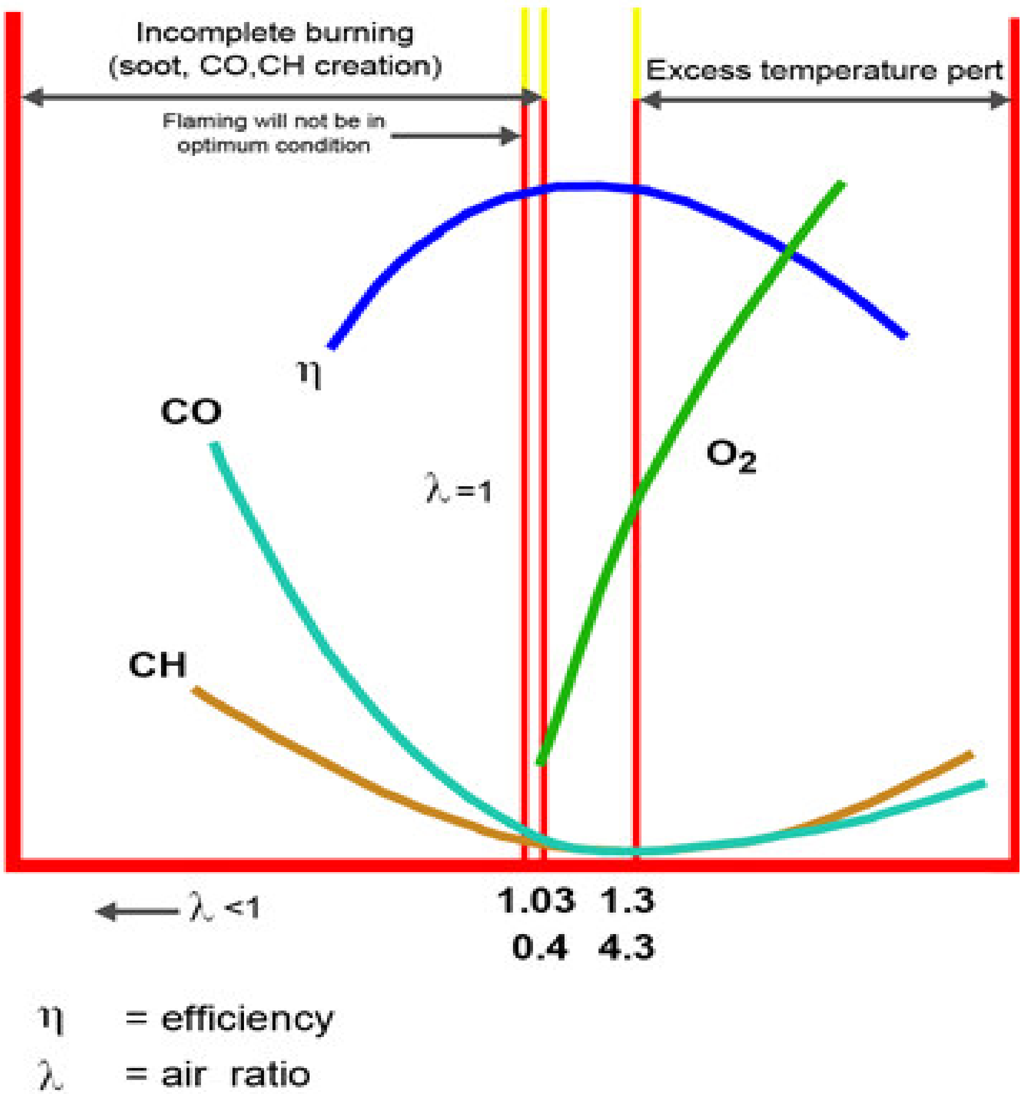

Figure 1. Graphical relation between λ and burning type.

Table 1. Range of λ for different air volume and burning type.

λ>1	**Air volume necessary for flume is not enough**	**Incomplete burning (soot, CO,CH creation)**
λ=1	Air volume is equal to theoretical air	Flaming will not be in optimum condition
λ=1/03	Excess air volume less	Flaming will be in optimum condition
λ=1/3	Excess air volume more	Flaming will be in optimum condition
λ>1/3	Excess air volume	Excess temperature loss

barely provided in practice. The analysis of the outlet gases from the furnaces can easily show the existence of minor amounts of CO in the free oxygen. In order to obtain the best conditions for fuel combustion, the amount of consumed air should be more than the required air by theory (Kurt, 2004). To calculate the amount of the additional air, the parameter of λ was defined as the ratio of the additional air volume to the required air volume by theory:

As it is shown in Figure 1, the best range to obtain optimal fuel efficiency and flaming condition is within1.03 <λ< 1.3. For values of λ lower than 1, that is, in the border of soot formation, the amount of CO and CH exponentially increase and consequently, the fuel thermal

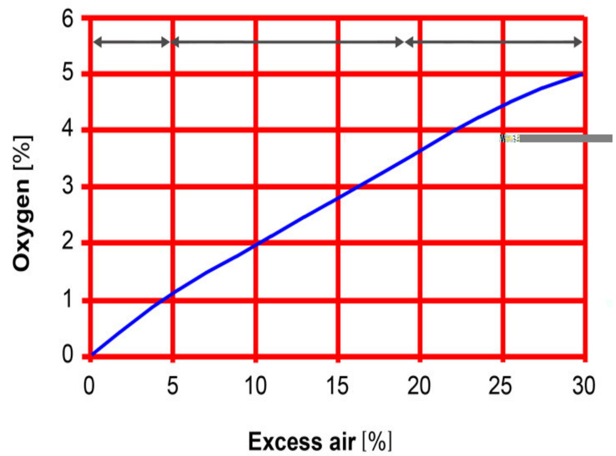

Figure 2. Relation between oxygen and excess air.

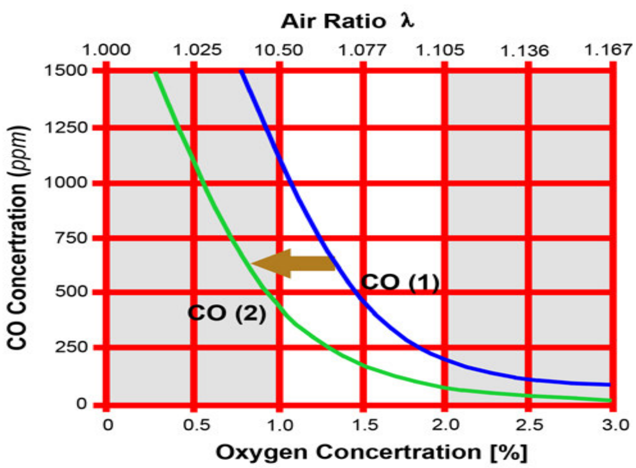

Figure 3. Variation of CO/O2 content.

efficiency η noticeably reduces.

For values of λ greater than 1.3, in spite of decrease in the CO and CH due to the oxygen increase, the thermal efficiency η again reduces due to the increase in the thermal loss. According to the presented graph, the range of λ is summarized as follows (Table 1).

Based on the type and design of torch, the amount of the extra air differs at each furnace. The measurement of the amount of oxygen at the end of the furnace may be the best parameter to make sure the optimality of combustion process and extra air sufficiency. As shown in Figure 1, the best amount of oxygen corresponds to 1.03 <λ< 1.3. According to the past experiences, the favorable operation of furnace is attainable when the amount of oxygen in the outlet gases is between 0.7 - 3.5. In the other words, the furnace operates in the stable state under such amount of oxygen. However, it is should be noted that the optimal amount of oxygen is between 1 - 1.5%. This is illustrated in Figure 2.

As it can be seen in Figure 2, the region including area A, contrary to area B, contains excess air. This means increase in the consumed energy due to thermal loss and occurrence incomplete combustion. The amount of excess air can be calculated using the following formula and the data of gas analyzer from the end of furnace. This formula is particularly useful when the amount of oxygen gets less than 1%. The percentage of excess air =1189(202-CO)/[N2-1.89(202-CO)]

DIFFERENT TYPES OF OUTLET POLLUTANT FROM CEMENT FURNACE

Oxygen and carbon monoxide

As previously mentioned at λ = 1, the amount of CO is not zero but it approaches to zero. In addition, the amount of oxygen is not equal to zero. This can be assigned to the flame dynamic and the mixing process of fuel and air. The relative location of CO graph may be properly considered as an index for the quality of the air and fuel mixture in the torch. This means that as the curve shifts to left, the mixing between air and fuel is more appropriate in the torch.

Therefore, the volume of CO can be applied to optimize λ in the furnace (Figure 3). More mixing between air and fuel make the furnace to work with lower additional air and consequently this indicates decrease in the consumed energy and emission of environmental pollutant gases (Figure 4).

Carbon monoxide, So2 and SH2

The relative positions of CO and So2 in the curve represent the concentration percentage of O2 and CO, the

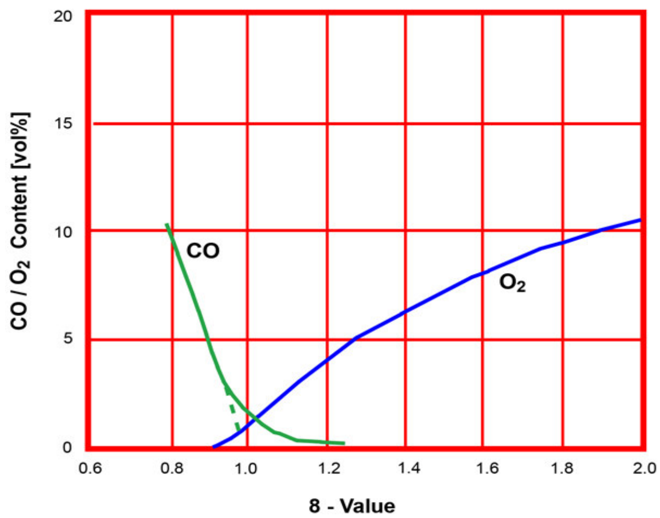

Figure 4. Relation between CO and oxygen concentration.

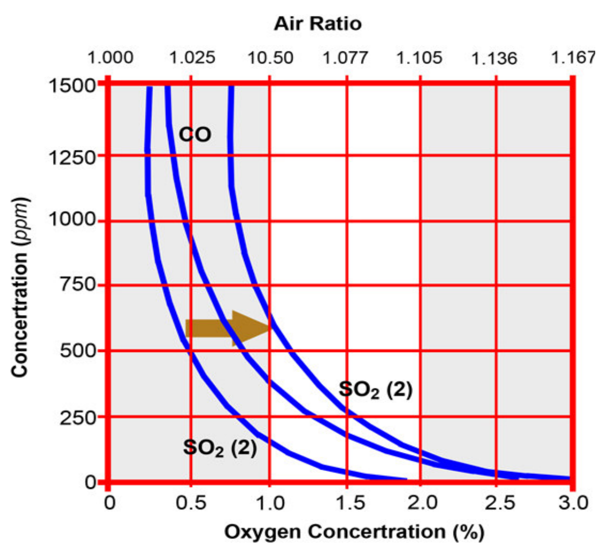

Figure 5. Variations of So2, CO and oxygen concentration.

amount of the redundant air and some data regarding the condition and position of materials heating in the furnace . In the favorable condition, the So2 curve lies in the left hand side of CO curve. Shifting the So2 curve to the right hand side of CO curve indicates that a reaction has been made between fuel and clinker (e.g. sulfate reaction to So2). This may cause decrease and increase in the clinker quality emission of So2, respectively. Therefore, it is necessary to prohibit reversed conditions in the furnace. SH2 rises along with other gases (Figure 5).

Nitrogen No2

In order to study No 2 changes and predict the heating

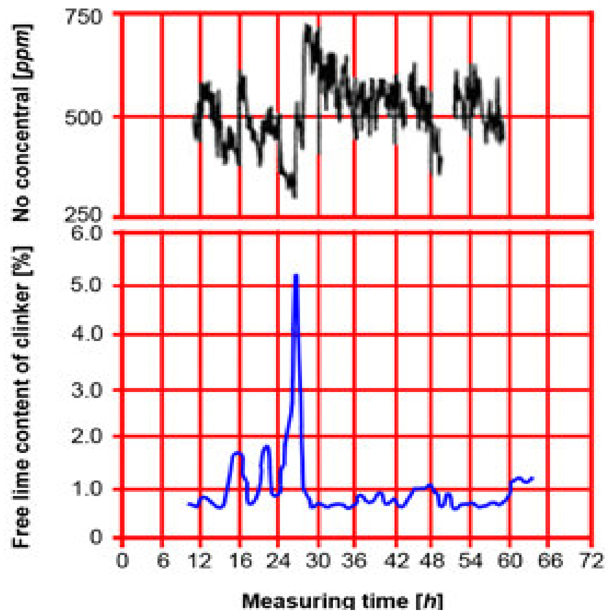

Figure 6. Free lime content of clinker and NO concentral verses time.

conditions affected by these changes, the sources of this gas is first discussed.

The thermal Nox: This compound is obtained from oxidizing nitrogen in the combustion state.

N2+O→NO+N Ea=76.5 kcal/mol
N+O2→NO+O Ea=6.3kcal/mol

As can be seen, due to the high activation energy of the reaction, high temperature is required to create Nox.

The Nox obtained from fuel burning: This compound is made from oxidizing nitrogen in the fuel and its dosage depends on the nitrogen existing in the fuel.

2N+O2→2NO

What seems noticeable in the formation of this compound is that any changes in the temperature fuel combustion directly influence the concentration of the outlet NO. This effect can be observed quickly in the analyzer at the end of the furnace. Figure 6 presents the relationship between the concentration of the furnace output gas and the free lime. As it is cited, the amount of the free lime of clinker has been increased by reduction in the NO percentage in the gray area. This is due to the decrease in the temperature of combustion in the furnace that leads to decrease and increase in the sintering process and free lime, respectively.

Carbon monoxide

Carbon monoxide, with the chemical formula CO, is a

Table 2. Destructive effects of carbon monoxide on human body.

Concentration	Time	Effects
5	20 min	Reaction of centre of nerves.
30	8 h	Damage to sharp-sighting and sharp witting.
100	2 - 4 h	Minor headache.
200	2 - 4 h	Feeling of pressure on forehead with minor headache.
500	2 - 4 h	Major headache, weakness and nausea.
1000	2 - 3 h	Darkness eye, major heart bit and unconscious.
2000	1 - 4 h	Death.

Table 3. Range of pollutions and solid particles per percentage of weight.

Range	Unit	Components
0 - 25	% of weight	SO3
0 - 10	% of weight	CL
0 - 40	% of weight	K2O
0 - 50	% of weight	CaO
0 - 10	% of weight	K
<1	% of weight	Na
0 - 10	% of weight	S

colorless and odorless gas. It is estimated that the annual amount of the rising carbon monoxide is about 35 million ton in the world and 20% of which is produced by human. Due to the Methane upper oxidization caused by the plants' deaths, 3.5 million of tons of CO enter the nature annually (Boudaghpour et al., 2007). The 95 - 98% of the amount of CO in a region can be related to human activities. The mixture of CO and blood hemoglobin produces hemoglobin carbon oxide COHb which leads to decrease in the ability of oxygen transmission by hemoglobin towards body's different tissues. This destructive pollutant affects the central neural system and causes some deficiencies in vision, heart and lung functions (Boudaghpour et al., 2007) (Table 2).

Nitrogen oxides

Nitrogen oxides classified as very active gases are made up of the combination of oxygen and nitrogen in different concentration. One of the most common compounds is nitrogen dioxide with floating particles in the air emerging like a brown- red layer over the cities. The reaction of this pollutant with organic chemicals and even ozone in the air produces a toxic substance which causes chromosomal changes and physically retarded newborns.

Sulfur oxides

Dioxides and trioxides of Sulfur exist in the atmosphere. Whenever their concentration reach to 0.3 - 1 ppm in the atmosphere, sense of taste will be affected .More than 80% of sulfur dioxides in the atmosphere can be assigned to the human activities and fossil fuel burning (Table 3).

Floating matters (Polluting matters) PM

Polluting materials are referred to the solid particles floating in the air which make the air darken. As the amount of polluting materials increase, the air seems to be dirtier. The size of the floating particles is between 0.1 - 50 micrometer; they easily get into breathing system through nasal cavities and on the way, the bigger particles are settled in the upper part and smaller ones penetrate into the depth of lungs and make the lung tissue destroy and weaken. The floating particles in the air can cause diseases like: infecting upper parts of the breathing system, heart problems and bronchitis (Sirje et al., 1998) (Tables 4 and 5).

The increasing trend of polluted gases has been seriously noticeable within the recent years. Each year, 2289762 tons of different type of pollutants release into Tehran's air only from moving sources. Of which, approximately 1976000, 21000, 105000 and 180000 tons are related to carbon monoxide, floating matters, nitrogen oxides and hydrocarbons, respectively.

Different methods for controlling and eliminating of pollutants and hazardous gases produced by cement industry

A great deal of floating particles and perilous gases are released into Tehran's atmosphere and environment during different heating procedures and cement producing in cement factories. Although most of the cement factories are located in the suburbs of Tehran, wind blowing and atmospheric pressure and temperature changes make the pollutants move towards city and cause harmful effects. Several methods have been proposed to control and eliminate the pollutants and hazardous gases. Applying these methods requires cooling of outlet gases. In what follows, some of these methods have been discussed.

Table 4. Percentage of emission of polluted gases related to concrete and cement production.

	Fossil fuel and Electricity	CO_2 emission	NO_X emission	Heavy metals
Cement	63%	79%	69%	88%
Aggregates	3%	1%	1%	1%
Steel	9%	4%	3%	-
Transportation of row materials	4%	3%	8%	<1%
Concrete production	15%	8%	5%	10%
Product transportation	6%	5%	14%	<1%
Total	100%	100%	100%	100%

Table 5. Load of environmental pollution of cement production in relation to cement.

	Cement content 280 Kg/m^3	Cement content 300 Kg/m^3	Cement content 350 Kg/m^3
CO2	190 kg	200 kg	240 kg
SO2	130g	140 g	160 g
NOX	790 g	840 g	980 g

Methods for controlling and eliminating of solid fine particles

The size of solid particles coming out of the cement heating furnaces has been estimated from 0.6 - 800 micron that breathing them can cause lung diseases.

Dry filter: A great amount of particles may be eliminated through putting a dry filter on the way of outlet gases. The filter can be either made up of special porous cloth or cellulose compounds and are capable to absorb a significant amount of suspended solid particles. This ability increases as the amount of porosity decreases. However, more resistance is introduced against gases flow by closing the pores.

Sticky filter: The fundamental function of sticky filters is completely different from dry filters. The flow of gas and outlet pollutants from the furnace are divided into a number of small flows after cooling in a way that some unevaporable and sticky obstacles are put on the way of the flow to absorb different sizes of solid particles.

Electrostatic elimination: After cooling the outlet gases, they are passed through an ionizing section in which the solid particles are charged. Then, gas and the charged particles are flown into the concentrating cells and due to the polar attraction, unlike electrical charges are condensed and eliminated on the concentrating surfaces (Table 6).

Controlling and eliminating hazardous gases

After eliminating solid particles from the cement heating furnaces, it is the time to vanish or reduce the toxic and harmful gases by means of different bio filters scrapers.

Bio filters: Bio filters normally contain a rectangular box placed on a fixed net and its inside is covered with a thickness of bed materials such as coal, bark, big seeds of soil, sands and gravel and shells. Bio filter is maintained throughout fertilizing bacteria on the bed materials. Then, harmful gases are passed through them to be absorbed by bacteria and crossed out of the outlet gases. This is an economic and cost-effective method. However, the living conditions of bacteria like PH, temperature, moisture and appropriate nourishment should be controlled. In some cases, a filter soaked in different chemicals is used in lieu of bio filter which reacts with damaging gases so as to absorb and eliminate them. This method is more expensive than bio filter one.

Leaking bio filter: One of the disadvantages of bio filters is to create and concentrate acid after absorbing harmful gases by bacteria. Most of compounds containing sulfur generate acids after decomposition. These acids are simply neutralized while passing through a bio filter.

Bio scraper: The more developed version of leaking bio filter is bio scraper employed to solve two problems of leaking bio filter: 1) Increase in the pollutants absorption 2) Increase in the contact time of bacteria with pollutants. One of the advantages of bio scraper is that polluted gases are not required to be moistured before refinement and consequently this cause reduction in the cost. In comparison with other bio reactors, a lower space is required and it is also possible to automatically control PH and nutrients. Furthermore, it is capable to refine polluted

Table 6. The standard amount of compounds making smog at the filter entrance.

Real condition	Normal operation	Unit	Comments
20	0 - 16	% of volume	O2
30	0 - 20	% of volume	CO2
40	0 - 30	Mg/NM3 dry air 11% 0.2	H2O
2.000	0 - 1/700	Mg/NM3 dry air 11% 0.2	SO2
150	0 - 100	Mg/NM3 dry air 11% 0.2	SO3
2.000	0 - 1/000	Mg/NM3 dry air 11% 0.2	NOX
250	0 - 50	Mg/NM3 dry air 11% 0.2	HCL
40	0 - 20	Mg/NM3 dry air 11% 0.2	HF
—	<0.1	Mg/NM3 dry air 11% 0.2	BR
25	0 - 20	Mg/NM3 dry air 11% 0.2	Organic Hydrocarbons
—	<0.1	Mg/NM3 dry air 11% 0.2	HCN
50	0 - 40	Mg/NM3 dry air 11% 0.2	NH3

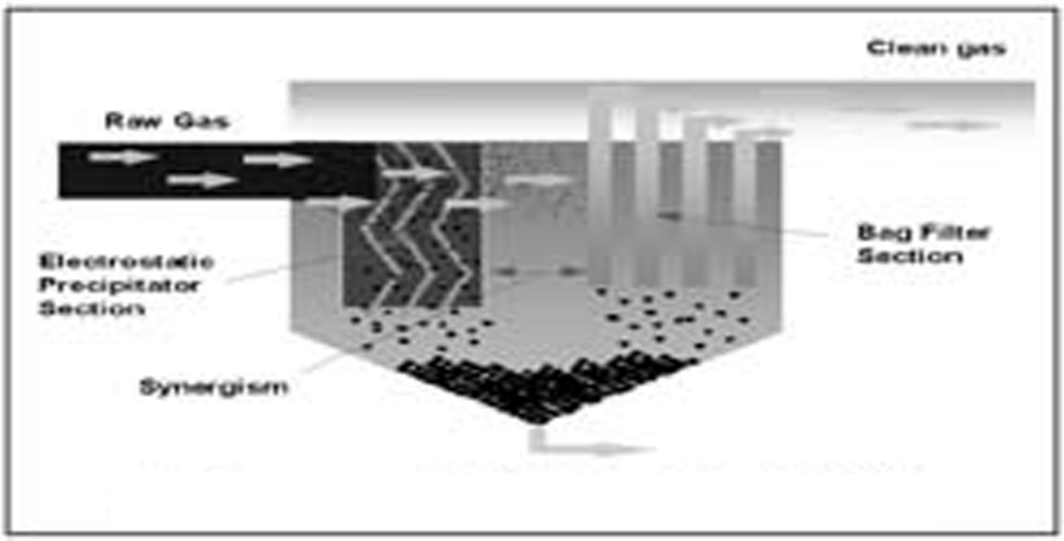

Figure 7. A schematic view of an advanced hybrid filter.

gases containing fine particles. The main disadvantages of bio scrapers compared to other bio reactors lie in higher cost of installation and maintenance and also too much growth of biological mass and consequently occurrence obstructing in the event of high recharge. In some cases, chemicals are utilized instead of bacteria in scrapers which in turn are costly.

Advanced hybrid filter: Electric and baghouse parts are separated and located in a casing in hybrid filter. Baghouse part is composed a number of bags similar to baghouse filter. Gas flow first enters into electric part; then about 90% of the dust is absorbed by the plates due to the electrostatic field. The main advantage of hybrid filter is that efficiency of dusting and amount outlet dust do not change sensible with variations of temperature, moisture and gas volume. Baghouse filter is the most sensitive part in the hybrid filter and needs continuous attention. Baghouse filter is made of fiberglass and to ensure protect again inlet gas and also increase of lifetime, it is coated with PTFE. The desirable performance of baghouse mainly depends on the temperature, compounds of inlet gases, filter pressure drop and the number of filter cease. Figure 7 Shows a schematic process of an advanced hybrid filter

RESULTS AND DISCUSSION

The experimental results show that advanced hybrid filter offers the following advantages over Electrostatic precipitator and baghouse filters:

Outlet dust lower than 10 mg/N3 m in the operation and cease in the furnace, milling row materials and short-time

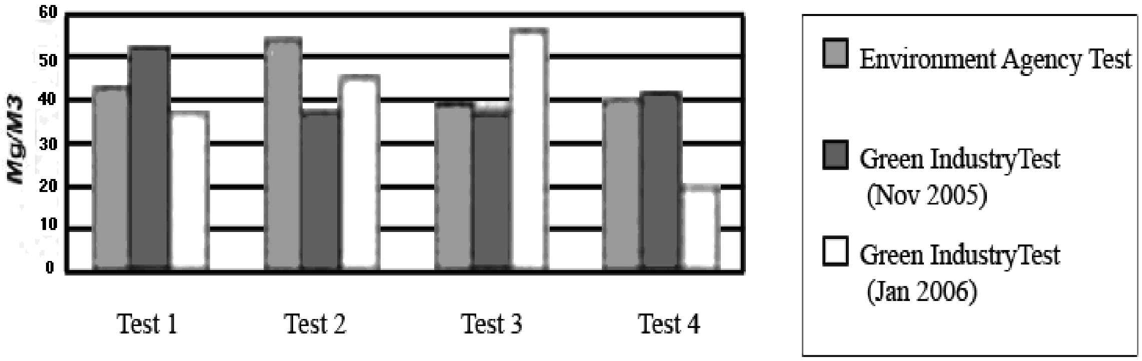

Figure 8. Results of dust measurement before installing advanced hybrid filter.

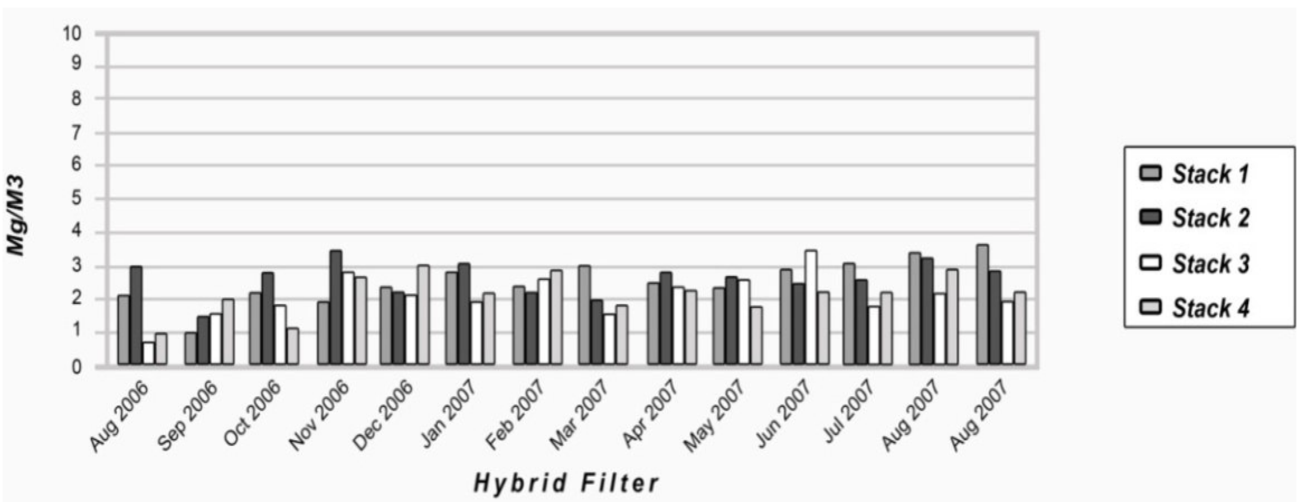

Figure 9. Results of dust measurement after installing advanced hybrid filters.

stop in the electric field due to the increase in the amount of CO in the outlet of furnace. Because prior to baghouse part, 90% of the inlet dust is absorbed by electric field, a decrease is seen in the consumption of compressed air to clean bags.

Decrease in the pulses of compressed air due to decrease of inlet dust to the baghouse part and consequently increase in the life time of bags (more than 4 years).

Saving in the cost and energy consumption due to the lower pressure drop and consumption of compressed air compared to baghouse filter. Figure 8 shows the results of dust measuring from electro filters by Isfahan Department of Environment and Azmoon Sanat Sabz Co.

Figure 9 shows the monthly measurement and analysisthe amount of outlet dust from 4 chimneys of advanced hybrid filters of Sepahan Cement Factory (since August of 2006) in conjunction with measured results by Azmoon Sanat Sabz Co.

The most important factors in the increase or decrease of outlet from hybrid chimney are as follows: CO_2 gas due to the following reaction in conjunction with gas obtained from fuel burning (gas or fuel oil) enters into hybrid filter.

The possibility of generation CO_2 increases as the amount of $CaCO_3$ increases.

$CaCO_3$ 900℃ →$CaO+CO_2$

Some portion of dust is absorbed by cooling tower and the remainder move toward electrostatic filters. Water splash in the cooling water is conducted in the cooling tower for different reasons. The most important reason is that the temperature of pre-heater is more than 180℃.

Varying tones of furnace load is characterized as an important factor in the increase or decrease of outlet of hybrid. In other words, increase of furnace load leads to increase in the outlet and vice versa. Also, the amount fuel should be increased proportional to increase of furnace load so as to maintain the mass balance of energy.

Furnaces fuel is also an important factor in the generation of outlet pollutants. Gas is a more fuel compared to oil fuel and consequently more pollutants are generated by

(b) (a)

Figure 10. View of dust dispersion (a) before installing advanced hybrid filters (b) After installing advanced hybrid filters.

fuel oil in the hybrid filters.

Accordingly, the amount discharge and outlet pollutants from chimney are not always constant and the obtained results should be presented by averaging with uncertainty.

Effective factors on the temperature changes of hybrid filters are as follows:

- One of the functions of the mill is to dry materials when the mill is not in the circuit. The outlet temperature of hybrids is more, because there is no thermal exchange with materials.
- The best range for the performance of hybrid occurs at the temperature between 100-120℃. The thermometer sensor confirms this issue during measurement and milling. The desirable temperature when the mill is and is not in the circuit is 180 and 100℃, respectively. It should be mentioned that the machine automatically cease the hybrid activity at the temperature lower than 85℃.
- The Chimney temperature was seen to decrease 5-10℃ in the winter compared to last summer (August 2006). This can be attributed mainly to decrease in the ambient temperature.
- Opening of fresh air gate after cooling tower cause decrease of suction in the system and consequently the filter temperature decreases. Since this is established to compensate pressure drop, it causes an increase in the engine speed of hybrid filters.
- Outlet of hybrids appears as water vapor in the cool months and when the mill is in the circuit, is more evident in the chimney exit. This happens due to the thermal exchange of chimney outlet (gases and dust) and cool air and occurrence of condensation. In this condition, chimney outlet appears as white dust and this is one of the most distinct differences between this type of outlet and dark outlet containing more dust. As it is clear in Figure 10, it should be noted that the water vapor after exiting from chimney travels more vertical distances due to its lighter weight compared to dust particles. However, as it is shown in figure 10, it is not clear as temperature rises, particularly at middle of day.

Conclusions and Comments

From the analytical and experimental results, the following conclusions can be reasonably drawn:

1) This research showed that harmful environmental effects of produced gases can be divided into parts: first, in the relation with those people working in the factories and are People exposed to factory environment and work in productive activities and are constantly in touch with polluted gases and pollutants. Hence, some special precautions should be taken to keep them healthy. And second, in regard with the environmental effects on Tehran. Although cement factories are located in the suburb, high concentration of hazardous gases, climate changes and wind blowing are the main factor that threat Tehran's air.
2) Growth in the vegetation cover around cement factories can be noticeably influential to absorb toxic gases and stop dispersing of pollutants.
3) Applying modern technology and abandoning used machineries would be a forward step to diminish such fatal gases.
4) Using absorbing chemicals may have significant influence to reduce or eliminate outlet polluted gases.
5) Optimizing the chimneys of outlet gases rising from furnaces and planning out solutions to refine gases and absorb before expanding through atmosphere have been highly recommended.
6) Applying dry and sticky filters noticeably cross out a great deal of output solid particles and remarkably decrease the damaging effects.
7) Regarding the specifications of any of the hazardous gases, the output polluted gases rising from the cement heating furnaces must be studied before refinement. If a certain gas, for instance, has a high temperature or enormous fine particles, a very appropriate pre-refining

procedure is recommended. Then, by keeping in mind the economic problems and the necessary level of refinement, the best option is held to refine the gas throughout bio filter.

8) If the flow of the outlet gases from the cement heating furnace contains pollutants producing acid, leaking bio filter or bio scraper is preferred the most. Provided it doesn't produce any acid and enough space is available, a common bio filter is applicable as well. And in case of a high efficiency of elimination, bio scraper will be an appropriate option.

9) Advanced hybrid filter achieved the best results for eliminating the dust excusing from chimneys of cement factory and produces suitable environmental situations.

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