

Atmospheric Pollutants and Trace Gases

Gaseous Contaminant Emissions as Affected by Burning Scrap Tires in Cement Manufacturing

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ABSTRACT

We studied the environmental impact (gaseous emissions) of using scrap tires as a fuel substitute at a cement plant that produces one million tons of cement per year. Using a combination of tires and coal as opposed to only coal caused variations in the pollutant emission rate. The study recorded a 37% increase in the rate of emission for CO, a 24% increase for SO₂, an 11% decrease for NO_x, and a 48% increase for HCl when tires were included. The rate of emission for metals increased 61% for Fe, 33% for Al, 487% for Zn, 127% for Pb, 339% for Cr, 100% for Mn, and 74% for Cu, and decreased 22% for Hg. On the other hand, the emission rate of organic compounds dropped by 14% for polycyclic aromatic hydrocarbons, 8% in naphthalene, 37% in chlorobenzene, and 45% in dioxins and furans. We used a Gaussian model of atmospheric dispersion to calculate the average pollutant concentration (1-h, 24-h, and annual concentrations) in the ambient air at ground level with the help of the ISC-ST2 software program developed by the USEPA. When tires were used, we observed (i) a 12 to 24% increase in particulate matter, this range considering the concentration variation depending on the average used (1-h, 24-h, and annual basis), 31 to 52% in CO, 22 to 34% in SO₂, 39 to 52% in HCl, 12 to 27% in Fe, -3 to 8% in Al, 30 to 37% in Zn, and 270 to 885% in Pb; (ii) a decrease of 8 to 13% in NO_x, 9 to 13% in polycyclic aromatic hydrocarbons, 6 to 7% in naphthalene, 32 to 39% in chlorobenzene, and 32 to 45% in dioxins and furans. The results obtained showed that the maximum ground-level concentrations were well within the environmental standards (for operation with only coal as well as for operation with a combination of coal and tires).

THE VALUE of scrap tires as an energy source in cement kilns (energy-content valorization) has recently attracted the attention of the scientific community, media, legislators, industries, and citizens. Indeed, scrap tires have proven to be an excellent fuel that can partially replace conventional fuels for clinker manufacturing. This technology offers environmental and economic advantages as previously described in Bredin et al. (1998). For example,

- Manufacturing costs are reduced by using scrap tires as fuel because they are cheaper than common fuels (coal, oil).
- Using tires in cement kilns is economical because such kilns are generally located near the places where tires are produced.
- It is less expensive to adapt cement plants to use scrap tires as fuel than to pay for incinerator construction. It should be noted here that an incinerator is not considered to be of energy content valorization, even if it supplies steam, because an incinerator is made to destroy waste and not to produce a durable good, as is the case in industrial plants (Bureau d'Audiences Publiques sur l'Environnement, 1997).
- Tires contain iron and other metals that are raw materials in cement manufacturing.
- In some countries (Canada, for example), the government pays for each tire valorized as a substitution fuel.
- New residues are not generated from tire valorization because the ashes produced are directly incorporated into the clinker.
- When tires are valorized in cement kilns, they are not accumulated in nature, thus avoiding potential fire accidents.
- When using tires as fuel, nonrenewable fuel (coal, oil) consumption is lower, thus contributing to natural resource preservation.

Even with improvement in reduction at the source, reuse, and recycling, new treatment units are required to manage waste.

Community support is needed to successfully implement new infrastructures for waste treatment or any other new technology (e.g., using waste as an alternate fuel). Scientists, engineers, and promoters of projects leading to waste treatment cannot make decisions related to their projects without first knowing the public's view on the subject. Delisle, quoted by Thibaudeau (1994), thinks that "citizens demand that scientists give them access to the knowledge necessary to evaluate the situation. They want to take hold of the elements allowing them to evaluate the situation. They want to

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take hold of the elements allowing them to make choices. Thus they want to know the risks and probabilities, and also the limits of the scientific analysis.”

The public's agreement and confidence can be obtained by including it to the decision-making process, through, for example, a watchdog committee. Citizens want to participate in the projects in order to make them socially acceptable. By taking part in committees, they have access to the information that will enable them to make a decision on what will take place in their own environment.

The Canadian cement factory's experience presented in this work shows that a watchdog committee can help to obtain the agreement and confidence of the public for projects related to waste incineration. Since the early 1990s, the cement plant showed an interest for alternate fuels such as waste. This company used waste oil since 1992 and used tires since 1994. With the factory's goal being to produce the highest quality cement at the most competitive price, waste valorization can help to achieve this goal with the savings on the fuel cost. In order to reconcile its economic vocation with social values such as the respect for natural resources and the community, the cement plant's guideline was the policy that “usage of combustible waste cannot in any way be a risk for the health and security of employees and the community, the respect of the environment and the quality and reliability of cement.” For the company, waste utilization for energy purposes also had its advantages for the environment (nonrenewable natural resource conservation and safe use of waste that would not be lost in nature), community (job stability in the region), employ-

ees (competitive position toward other cement plants is improved because of reduced production costs), and shareholders (improved return).

The goal of this paper was to quantify pollutant emissions and study their atmospheric dispersion in order to ensure that emissions and ground-level maximum concentrations coming from this technology would not exceed environmental regulations. We are not aware of any comprehensive study on the ground-level concentrations of pollutants emitted from cement stacks in comparison with emission standards adopted in Canada.

MATERIALS AND METHODS

Pollutant Emission to the Atmosphere

We studied the environmental impact of energy-content recovery of scrap tires by comparing the emission of several pollutants when the fuel being used for cement manufacturing is coal or a combination of coal and scrap tires. When the fuel being used was coal, the particulate matter and metals came from eight stacks (kiln and cooling unit stacks), whereas the other compounds were released from only four kiln stacks. For the scrap tires, one of the kilns operates with coal and the three others are run with the mixture of coal and tires. This resulted in particulate matter and metals being emitted from six of the stacks (coal and tires) and two stacks (coal). The remainder of the pollutants were emitted from three stacks (coal and tires) and one stack (coal).

The characteristics of gaseous emissions before being dispersed into the atmosphere, whether using pure coal as fuel or a mixture of coal and scrap tires, can be found in Table 1 (average values of different measurements and various samples). Gaseous samples were collected at the stack's exit three

Table 1. Velocity, temperature, and volumetric flow rate of gaseous effluents and pollutant concentrations at the stack's exit for both modes of kiln operation (coal or coal and tires).

Parameters	Coal		Coal and tires	
	Kilns	Cooling units	Kilns	Cooling units
		Effluent		
Velocity, m/s	4.15	8.99	4.14	10.61
Temperature, K	565	366	546	357
Flow rate, stp [†] m ³ /s	19.95‡, 20.16§, 20.37¶	18.30	20.22‡, 20.32§, 20.37¶	22.18
		Pollutants		
PM, mg/m ³ #	99.2	56.2	106.5	64.9
Metals, µg/m ³				
Fe	873.0	850.7	1862.4	993.7
Al	745.2	924.3	1284.0	898.7
Zn	185.1	59.5	1700.1	65.3
Pb	120.8	14.1	334.8	18.3
Cr	48.0	14.3	315.5	16.1
Hg	55.1	0.55	37.7	0.90
Mn	27.5	25.6	87.3	27.7
Cu	3.93	3.84	11.2	3.07
Gases, mg/m ³				
NO _x	1754.4	–	1483.9	–
SO ₂	696.8	–	905.2	–
CO	155.4	–	228.0	–
HCl	9.68	–	15.80	–
Organics, µg/m ³				
PAH#	83.5	–	68.4	–
Naphtalene	76.3	–	68.3	–
Chlorobenzene	1.72	–	0.88	–
Dioxins and furans	0.0010	–	0.0004	–

[†] Standard temperature and pressure.

[‡] For PM, metals, and non-condensable gases.

[§] For HCl.

[¶] For organic compounds.

PM, particulate matter; PAH, polycyclic aromatic hydrocarbons.

different days by Expertises en Environnement, Arthur Gordon Ltée, Saint-Bruno de Montarville (Canada) (Demers, 1994) and the Ministry of the Environment of Quebec (Canada) (Bougie, 1993). More details about sampling and analysis of gaseous effluents can be found in these references. Particulate matter and non-condensable gases (CO, SO₂, and NO_x), as well as aromatic hydrocarbons, are typically found in combustion gases. The metals selected for study had to be emitted in large quantities, fall within the standards (when coal is used), and be present in tire composition. Finally, compounds containing chlorine also were considered, such as HCl, chlorobenzene, polychlorodibenzodioxines, and polychlorodibenzofurans, for their potentially dangerous character (chlorine is an element present in coal and tires).

Atmospheric Dispersion of Pollutants

We calculated the pollutant concentrations at ground level with the USEPA ISC2-ST (Industrial Source Complex, Version 2, Short Term) software. This software calculated the average pollutant concentration at receptor points on a model grid, resulting from an industrial complex's continuous emissions and encompassing periods between 1 h and 1 yr. It applies in an urban or rural setting, on flat or complex terrain. First, the software calculated, with the help of the Gaussian equation, the 1-h concentration at each receptor's point. This was done for each receptor over a period of one year. The 24-h concentration represents the average of 24 hourly concentrations, therefore giving 365 24-h concentrations per receptor per year. The annual concentration is calculated by making the average of 8760 hourly concentrations, which gives one annual concentration per receptor per year.

The data required for the model were the following (Bredin, 1997):

- (i) Meteorological data. The meteorological data (i.e., cloud ceiling, wind speed, ambient temperature, cloud cover, and wind direction) were provided by Environment Canada from the weather station closest and most representative of the study site. The mixture height was measured with a sounding balloon in an aerological station having similar climatic conditions as the study site. With this information, it was possible to determine the class of atmospheric stability.

- (ii) Source characteristics. The stack height and diameter were 61 and 3.5 m for kilns, and 16 and 1.8 for cooling units, respectively. The elevation of stacks above sea level was 55 m. The locations in meters (x, y) of stacks on the model grid were (0, 0), (-20, 0), (-40, 0), and (-60, 0) for kilns, and (0, 195), (-20, 195), (-40, 195), and (-60, 195) for clinker cooling units.
- (iii) Effluent and pollutant characteristics. The parameters relating to gaseous effluents at the stack exits were volumetric flow rate, velocity, and temperature as well as the concentration of each pollutant.
- (iv) Data relating to the building downwash effect. The presence of buildings disturbs the air's flow. The local air velocity changes when it passes over a disturbing building. When the height of the stacks is 2.5 times higher than the building, it is assumed that air disturbances caused by these buildings do not affect the dispersion of pollutants emitted by the stacks. As a consequence, buildings higher than 6.4 m disturbed the dispersion of pollutants coming from the cooling unit stacks and buildings higher than 24.4 m disturbed the dispersion of pollutants coming from both kiln and cooling unit stacks. Therefore, we concluded that there were 7 disturbing buildings for the kiln stacks and 15 buildings for the cooling unit stacks.
- (v) Receptor location. One of the kilns was located at the center of the grid. The links were square and were 500 × 500 m. The grid measured 10 × 10 km, which means that there were 440 receptor points. Each receptor (where ground-level concentrations were calculated with the model) was located at each node point of the grid. The altitude of each receptor was taken into account with topographic maps of the modeled area (altitudes were between 25 and 75 m).

It should be noted that throughout this paper, maximum concentration is referred to as *ground-level maximum concentration*, which is computed in the model calculations.

RESULTS AND DISCUSSION

Pollutant Emission to the Atmosphere

Table 2 shows the amount of pollutants per kilogram of clinker emitted to the atmosphere when using as

Table 2. Amount of pollutants emitted to the atmosphere through the stacks per kilogram of clinker produced before and after the scrap tire valorization.

Pollutant†	Coal			Coal and tires		
	Kilns	Cooling units	Total	Kilns	Cooling units	Total
PM, mg/kg	166.4	86.5	252.9	177.4	112.4	289.8
Metals, µg/kg						
Fe	1464.6	1309.2	2773.8	2741.3	1717.4	4458.7
Al	1250.2	1422.5	2672.7	1950.1	1612.8	3562.9
Zn	310.5	91.6	402.1	2245.8	114.2	2360.0
Pb	202.7	21.7	224.4	477.6	31.0	508.7
Cr	80.5	22.0	102.5	422.5	28.0	450.5
Hg	92.4	0.85	93.3	71.2	1.5	72.7
Mn	46.1	39.4	85.5	122.9	48.6	171.5
Cu	6.6	5.9	12.5	15.9	5.8	21.7
Gases, mg/kg						
NO _x	2943.4	—	2943.4	2628.3	—	2628.3
SO ₂	1169.0	—	1169.0	1446.7	—	1446.7
CO	260.7	—	260.7	356.0	—	356.0
HCl	16.4	—	16.4	24.4	—	24.4
Organics, µg/kg						
PAH	143.0	—	143.0	123.6	—	123.6
Naphthalene	130.7	—	130.7	120.4	—	120.4
Chlorobenzene	2.9	—	2.9	1.9	—	1.9
Dioxins and furans	0.0017	—	0.0017	0.00094	—	0.00094

† PM, particulate matter; PAH, polycyclic aromatic hydrocarbons.

fuel only coal or a mixture of coal and scrap tires. The calculations were achieved assuming there was continuous operation throughout 8 mo per year in order to take into consideration that kilns stop occasionally (i.e., breakdowns and maintenance).

Particulate matter emission resulting from the kilns was 166.4 mg/kg of clinker when coal was used for fuel and 177.4 mg/kg of clinker when a mixture of coal and tires was used for fuel (i.e., a 7% increase). Given that the Québec standard permits an emission rate of 500 mg/kg of clinker (Anonymous, 1993), this shows that the cement kiln respected environmental regulations and did so well within the boundaries (only 33 and 35% of the allowable emission). For the cooling units, particulate matter emission was 86.5 mg/kg of clinker when coal was the fuel and 112.4 mg/kg of clinker when a mixture of coal and tires was the fuel (i.e., a 30% increase). Given that the Québec standard permits an emission rate of 350 mg/kg of clinker (Anonymous, 1993), this shows that the cement kiln respected environmental standards (only 25 and 32% of the allowable emission). Therefore, the total particulate matter emission was 252.9 mg/kg of clinker and 289.8 mg/kg (i.e., a 15% increase when using scrap tires), as shown in Fig. 1. This increase was slightly lower than the results presented by Clark et al. (1993), which stated a 20% increase in particulate matter emission.

Figure 1 also shows emissions of non-condensable gases NO_x , SO_2 , and CO before and after scrap tire valorization. It should be noted that NO_x was the pollutant emitted in the greatest amount, and was significantly reduced from 2.94 to 2.63 g/kg (i.e., a decrease of 11%) when tires were valorized. The SO_2 emission was 1.17 g/kg of clinker when coal was the fuel and 1.45 g/kg of clinker when the mixture of coal and tires was the fuel

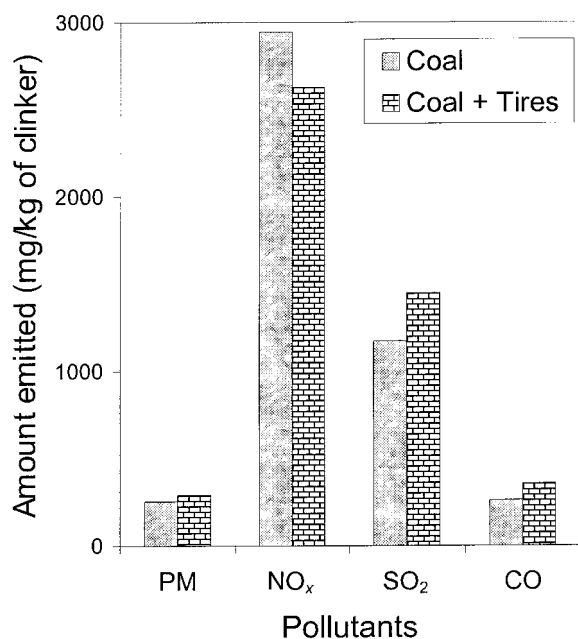


Fig. 1. Total emissions of particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and carbon monoxide (CO) through the stacks when coal or coal and tires was used as fuel.

(i.e., a 23% increase). The CO emission increased from 261 to 356 mg/kg (i.e., a 37% increase). According to Lemieux (1994), burning fuel derived from tires did not result in a significant increase in CO emission, whereas Siemering et al. (1991) estimated this increase to be 40%, and Clark et al. (1993) reported a 33% increase. The latter also reported a decrease in sulfur dioxide and nitrogen oxides (40 and 26%, respectively). According to Kearney, cited by Bredin (1997), there is no change in SO_2 and CO emission, but a 10% reduction in NO_2 emission. The difference in results can be explained by the fact that sulfur dioxide and nitrogen oxide emission depends on the quantity of these elements present in the fuel and the combustion efficiency, which is also an important criterion in carbon monoxide production. On the other hand, hydrogen chloride sustained an important increase, from 16 to 24 mg/kg (i.e., a 48% increase), because chlorine is an element found in higher quantities in tires than in coal (Table 2).

Emitted metals were assumed to be adhered to particulate matter (Von Seebach and Tompkins, 1991). For the kilns, an increase in metal emission when scrap tires were used as fuel was of utmost importance. The most drastic change was seen in zinc, which is an important constituent of tires: the emission was 7.2 times greater when tires were used (2246 vs. 311 $\mu\text{g}/\text{kg}$) (Table 2). Lemieux (1994) estimated a 2.1% zinc content for a fuel derived from tires without the ply. The Cr emission was 5.2 times greater (422 vs. 81 $\mu\text{g}/\text{kg}$), that of Mn was 2.7 times higher (123 vs. 46 $\mu\text{g}/\text{kg}$), and that of Pb was 2.4 times greater (478 vs. 203 $\mu\text{g}/\text{kg}$) when tires were used. The relative variation of the emission for Fe and Al was less (1.9 and 1.6 times greater, respectively), but the absolute value significantly increased because these metals were present in higher concentrations (2741 vs. 1465 $\mu\text{g}/\text{kg}$ for Fe and 1950 vs. 1250 $\mu\text{g}/\text{kg}$ for Al). When scrap tires were used, a 133% increase in metals emitted from kilns was noted. For the cooling units, the variation in emissions was less important than that found in kilns. An increase within the range 15 to 45% was observed for almost all the metals, except for Cu (almost invariable) and Hg (76%) when scrap tires were used. When scrap tires were used, a 22% increase in metals emitted from clinker cooling units was noted. Figure 2 shows the total amount of the six metals with higher emissions, when taking into account all the sources (kiln stacks and cooling unit stacks). It is clear that the iron and zinc amounts significantly increased because they are present in appreciable quantities in scrap tires (iron comes from steel structure and zinc from zinc oxide added in the tire vulcanization process). The total amount of emitted Fe increased from 2.8 to 4.5 mg/kg (i.e., a 61% increase) when using scrap tires, that of Al increased from 2.7 to 3.6 mg/kg (i.e., a 33% increase), and that of Zn increased 0.4 to 2.4 mg/kg (i.e., a 487% increase). When scrap tires were valorized, we detected increases of 74% for Cu, 100% for Mn, 127% for Pb, and 339% for Cr. Only the amount emitted of Hg decreased (21%). The total amount of metals coming from all the stacks increased approximately by 82%.

The amount emitted of all the organic compounds

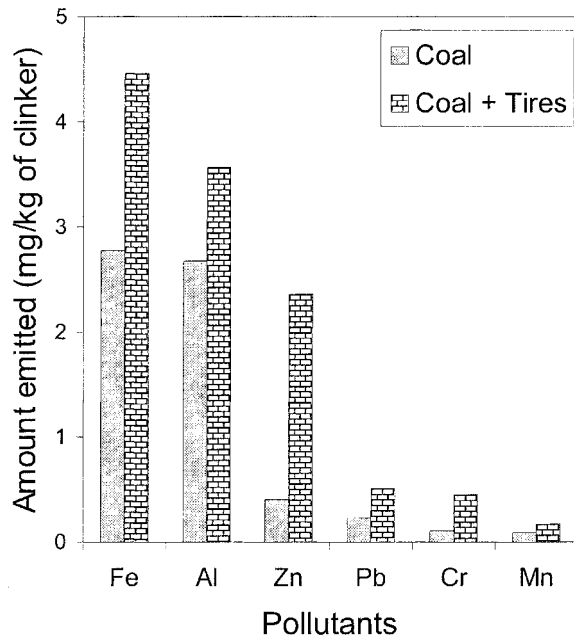


Fig. 2. Total emissions of six metals (Fe, Al, Zn, Pb, Cr, and Mn) through the stacks when coal or coal and tires was used as fuel.

studied decreased when scrap tires were used: polycyclic aromatic hydrocarbons (from 143 to 124 $\mu\text{g}/\text{kg}$, a 14% decrease), naphthalene (from 131 to 120 $\mu\text{g}/\text{kg}$, an 8% decrease), chlorobenzene (from 2.9 to 1.9 $\mu\text{g}/\text{kg}$, a 37% decrease), and dioxins and furans (from 1.7 to 0.9 ng/kg , a 45% decrease). It should be noted that dioxins and furans are expressed as equivalent to 2,3,7,8-tetrachlorodibenzodioxin.

Atmospheric Dispersion of the Pollutants

In general, the maximum concentration trends of increase or decrease of all pollutants (with the exception of Al and Hg) were similar for 1-h, 24-h, or annual average concentrations, even though absolute values were not identical, as seen in Table 3.

First, it has to be observed that the maximum annual concentration was lower than the maximum 24-h concentration, which was lower than the maximum 1-h concentration. For example, SO_2 maximum concentrations when the cement plant operated with scrap tires were 3.37 for the annual, 82.8 for the 24-h, and 715.2 $\mu\text{g}/\text{m}^3$ for the 1-h maximum concentrations. This demonstrates the effect of concentration reduction over 24 compared with 1 h (due to the change in wind direction and intensity); this phenomenon was stronger for annual concentrations. Because of this, and also taking into account the pollutant toxicity, environmental regulations must be different. It is obvious that if discrete environmental incidents have to be considered, the magnitude of maximum 1-h concentrations is needed, whereas if average concentrations over a longer period are needed, maximum 24-h or annual concentrations must be taken into consideration. In general, the maximum 1-h concentrations were six to seven times higher than those of maximum 24-h concentration for metals and eight to nine times higher for gases and organic compounds. On the other hand, the maximum 1-h concentrations were 37 to 44 times higher than those of maximum annual concentration for metals and 190 to 220 for gases and organic compounds. Finally, the maximum 24-h concentrations were six to eight times higher than those of maximum annual concentration for metals and 20 to 25 for gases and organic compounds.

As previously mentioned, it is suitable to analyze the maximum 1-h concentrations when discrete environmental events occur. The maximum 1-h concentration of CO and SO_2 increased by 52 and 34%, respectively, whereas NO_x experienced a 13% decrease when scrap tires were used. The maximum Fe content increased by 18% whereas that of Al remained almost invariable. The maximum Zn and Pb concentrations increased significantly (32 and 270%, respectively), indicating their presence in tires. Manganese behaved in a special way because the emission coming from the stacks of clinker

Table 3. Maximum 1-h, 24-h, and annual concentrations computed at ground level for both modes of kiln operation (coal or coal and tires).

Pollutant†	Maximum concentrations					
	1-h concentration		24-h concentration		Annual concentration	
	Coal	Coal and tires	Coal	Coal and tires	Coal	Coal and tires
PM, $\mu\text{g}/\text{m}^3$			92.0	102.7	14.8	18.4
Metals						
Fe, $\mu\text{g}/\text{m}^3$	9.12	10.8	1.39	1.56	0.22	0.28
Al, $\mu\text{g}/\text{m}^3$	9.91	9.97	1.51	1.46	0.24	0.26
Zn, ng/m^3	637.8	844.0	97.3	126.1	15.9	21.8
Pb, ng/m^3	50.0	185.5	7.67	29.2	0.47	4.63
Cr, ng/m^3	44.0	173.5	23.3	29.3	3.81	4.82
Hg, ng/m^3	22.8	16.3	3.59	2.84	0.30	0.37
Mn, ng/m^3	274.1	300.6	41.8	44.0	6.69	7.85
Cu, ng/m^3	11.8	35.0	6.25	5.31	1.00	0.94
Gases, $\mu\text{g}/\text{m}^3$						
NO_x	1402.2	1224.4	163.1	149.5	7.29	6.58
SO_2	533.3	715.2	64.5	82.8	2.77	3.37
CO	118.5	179.9	14.3	20.4	0.62	0.81
HCl			0.90	1.37		
Organics						
PAH, ng/m^3	64.9	56.3	7.81	6.88	0.34	0.31
Naphthalene, ng/m^3	59.3	55.1	7.13	6.73	0.31	0.29
Chlorobenzene, pg/m^3			160.7	98.1	6.92	4.64
Dioxins and furans, fg/m^3			94.8	51.8	3.95	2.67

† PM, particulate matter; PAH, polycyclic aromatic hydrocarbons.

cooling units was higher in comparison with that of metals globally emitted in greater amounts, such as Pb, Cr, and Hg. Remember that the building downwash effect is more important for the emissions coming from the cooling unit stacks, which have a lower height. Therefore, because the cooling unit stack emissions contained more Mn than Pb, Cr, or Hg, the 24-h maximum ground-level concentrations followed the same trends. When kiln operation was carried out with coal, the maximum 1-h concentration at ground level of Mn was 274 ng/m³, whereas those of Pb, Cr, and Hg were 50, 44, and 23 ng/m³, respectively. By taking into consideration the total amount emitted to the atmosphere without building downwash effects, the maximum 1-h concentration of Mn should be lower than 23 ng/m³, but actually is 274 ng/m³. On another hand, when the kiln operation was carried out with coal and tires, the maximum 1-h concentration at ground level of Mn was 301 ng/m³, whereas those of Pb and Cr were 186 and 174 ng/m³, respectively. By taking into consideration the total amount emitted to the atmosphere, the maximum 1-h concentration of Mn should be lower than 174 ng/m³, but actually is 301 ng/m³. This means that the maximum 1-h concentration of Mn was higher than the expected value when considering the total amount emitted, whether pure coal or a mixture of coal and tires was being used. This was due to the building downwash effect on effluent gases coming particularly from the cooling unit stacks. Similar conclusions were found with maximum 24-h and annual concentrations. Finally, the maximum concentration was reduced by 13% in the case of polycyclic aromatic hydrocarbons and 7% in naphthalene when scrap tires were valorized.

In order to take into consideration an average concentration during moderate time periods, the maximum 24-h and annual concentrations should be considered. The maximum 24-h concentration of particulate matter increased by 12%, and that of CO, SO₂, and HCl increased by 43, 28, and 52%, respectively, whereas NO_x experienced an 8% decrease, when scrap tires were used as substitution fuel (Table 3). The maximum Fe, Zn, and Pb contents increased by 12, 30, and 280%, respectively, whereas that of Al remained almost invariable. The maximum 24-h concentration was reduced by 39% for chlorobenzene, 12% in polycyclic aromatic hydrocarbons, and 6% in naphthalene. The content in dioxins and furans was reduced by 45% when operating the kilns with coal and tires instead of only coal.

In order to take into consideration an average concentration during long time periods, the maximum annual concentrations should be considered. The maximum annual concentration of particulate matter increased by 24%, and that of CO and SO₂ increased by 31 and 22%, respectively, whereas NO_x experienced a 10% decrease, when scrap tires were used as substitution fuel. The maximum Fe, Al, Zn, and Pb contents increased by 27, 8, 37, and 885%. The maximum concentration was reduced by 33% for chlorobenzene, 9% in polycyclic aromatic hydrocarbons, and 6% in naphthalene. The content in dioxins and furans was reduced by 32% when operating the kilns with coal and tires instead of only coal.

The maximum 1-h concentrations were mostly located at positions (500, -500) and (-500, 500) when either coal or the mixture of coal and tires was used as fuel [only maximal Cr and Cu were placed at (500, 500)]. The maximum 24-h concentrations were mostly located at positions (500, -500) and (0, 0) when either coal or the mixture of coal and tires was used as fuel [only Fe was placed at (500, 500)]. Therefore, the distance from the factory at which maximum 1-h and 24-h concentrations were reached was around 700 m. On the other hand, the maximum annual concentrations were located at positions (500, 500) and (-1500, -1500) when either coal or the mixture of coal and tires was used as fuel. Therefore, the distance from the factory at which maximum annual concentrations were reached ranged approximately between 700 and 2100 m.

A part of the receptors with maximum concentrations was found on the southwest-northeast axis, which corresponds to the direction of the dominating winds, whereas the other receptors were found on the northwest-southeast axis, due to the building downwash effect.

Figure 3 clearly shows that particulate matter, sulfur dioxide, and nitrogen oxides respected the environmental standards (Anonymous, 1986) with respect to maximum 24-h concentration. When using a coal and tires combination, the maximum 24-h particulate matter concentration was 68% of the standard, that of sulfur dioxide was as low as 28%, and that of nitrogen dioxide was 72%. The 24-h concentrations of the other pollutants were also lower than the environmental standards. Figure 4 illustrates that environmental standards were widely respected when annual concentrations were considered. The maximum particulate matter concentration (for coal and tires) was only 26% of the standard, and

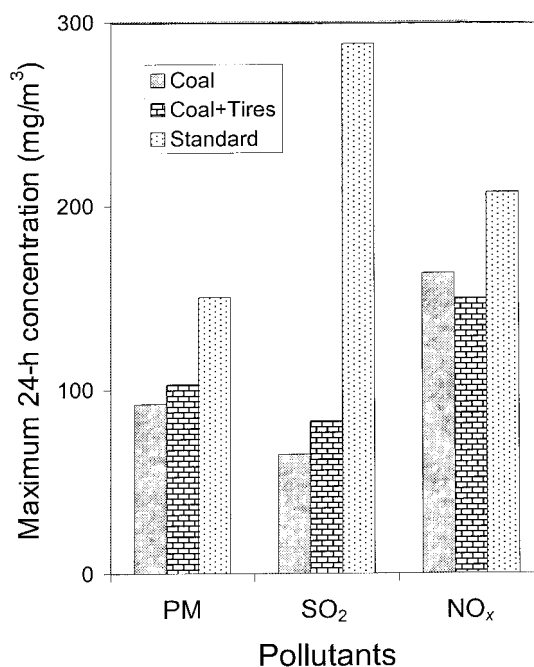


Fig. 3. Maximum 24-h concentration at ground level and Quebec environmental standards for particulate matter (PM), sulfur dioxide (SO₂), and nitrogen oxides (NO_x) when coal or coal and tires was used as fuel.

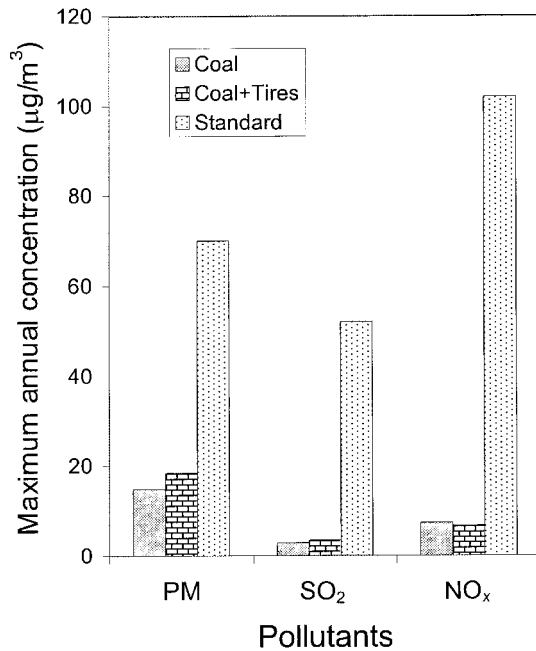


Fig. 4. Maximum annual concentration at ground level and Quebec environmental standards for particulate matter (PM), sulfur dioxide (SO₂), and nitrogen oxides (NO_x) when coal or coal and tires was used as fuel.

those of sulfur dioxide and nitrogen oxide were as low as 6%. Consequently, maximum annual concentrations were more reduced relative to environmental standards than maximum 24-h concentrations. The annual concentrations of the other pollutants were also lower than the environmental standards. On another hand, maximum 1-h concentrations were also lower than environmental standards. Maximum 1-h CO concentrations were 118 to 180 µg/m³, whereas the standard is 34 000 µg/m³. Maximum 1-h SO₂ concentrations were 530 to 715 µg/m³, whereas the standard is 1310 µg/m³. Finally, maximum 1-h concentrations of polycyclic aromatic hydrocarbons were 56 to 65 pg/m³, whereas the standard is 190 pg/m³.

In conclusion, even though the concentrations of certain pollutants increased when using tires as a source of fuel, the environmental standards were still well respected.

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