REDUCTION OF AIR POLLUTANTS BY OPERATIONAL CONTROLS IN INDUSTRIAL BOILERS

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1. Preamble

This report is produce under SIDA´s international training program in air pollution management that took place within august 31th to October 4th 2009 at SMHI´s headquarters Norrköping, Sweeden.

Part of my job, as an environmental engineer, is to support industries to comply with Colombian environmental laws, thus this IPW focuses on comparing emissions of different type of industries with boilers that work with different types of fuels, and propose good practices and technological changes to make sure they actually comply.

2. Executive Summary

The present report proposes an analysis of atmospheric emissions of four companies in the region of eastern Antioquia, which have four different types fuels used in their boilers: wood scrap, bituminous coal, Liquefied Petroleum Gas and industrial waste oil. It was necessary to gather the results of recent stack sampling in all four industries and identify those emission sources that do not meet quality standards permitted by Colombian laws and regulations in terms of concentrations of PM, NOx, SO2 and CO2 , with the objective of providing recommendations for improvements of this emissions in case of no compliance.

The results of the stack sampling are individual data taken no longer than three years ago, since it was not possible to have averages due to lack of information. The environmental authority does not require these industries to sample the stacks very often but only every two or three years depending on the impact they consider it causes.

To estimate the level of compliance, the standards limits required by Resolution 909/2008 (given in mg/m^3), where taken as main references, but at the same time, this data was compared to the values of emission factors presented by EPA in its AP42 publication, converted to the same units (mg/m3) to have an equivalent basis of comparison.

This assessment shows that

1- Wood bark/scrap boiler does not comply with limit values according to Colombian law and neither with EPA emission factors.
2- LPG boiler complies largely with Colombian Law, however the emission of PM those not meet the EPA Emission Factor
3- Bituminous Coal Boiler does not meet Colombian standards on PM, but regarding EPA´s emission Factor it does.
4- Industrial waste oil boiler complies largely with both Colombian law and EPA emission factors.

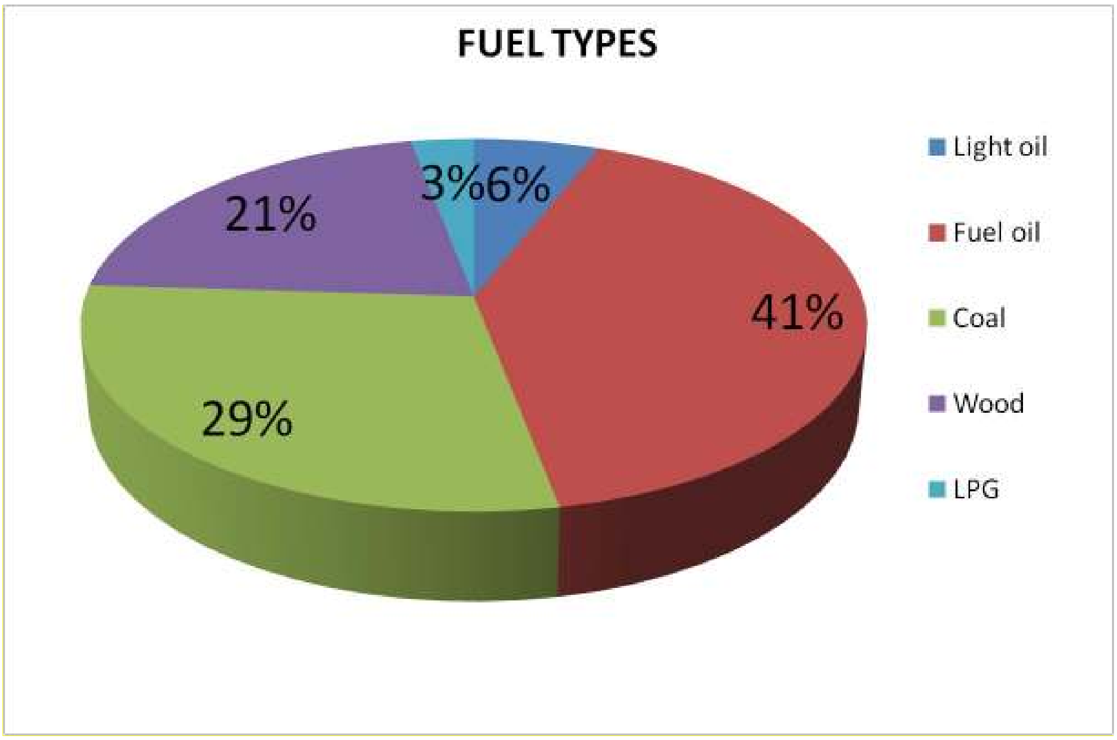
Although a raw estimation was made through AIRVIRO simulation model for a city with similar characteristics, it is necessary a more accurate emissions impact simulation to determine whether or not studied sources are affecting air quality in the region. However the four boilers have given impacts below 1 $\mu g/m^3$ in terms of annual average for PM10. According to the Airviro simulations, the highest daily average to be expected from the largest source (I1) is below 10 $\mu g/m^3$, which should be compared to the EPA limit value of 150 $\mu g/m^3$.

3. Introduction and objectives of the study

Historic data shows that since 1998 to 2005, the air quality standards for this region have complied with international law, the same suggested for Colombia: the annual arithmetic average does not exceed 50 $\mu g/m^3$, except for one of the three monitoring stations, that in 1999 reached a value of 61.10$\mu g/m^3$, due to a major highway construction in this area. However the reported data has never exceeded the daily EPA limit of 150 $\mu g/m^3$.

Based on the results obtained on these monitoring stations, it´s safe to say that this region still has a good air quality but it is necessary to continue working to keep it that way and prevent it´s deterioration from industrial development and massive vehicle circulation.

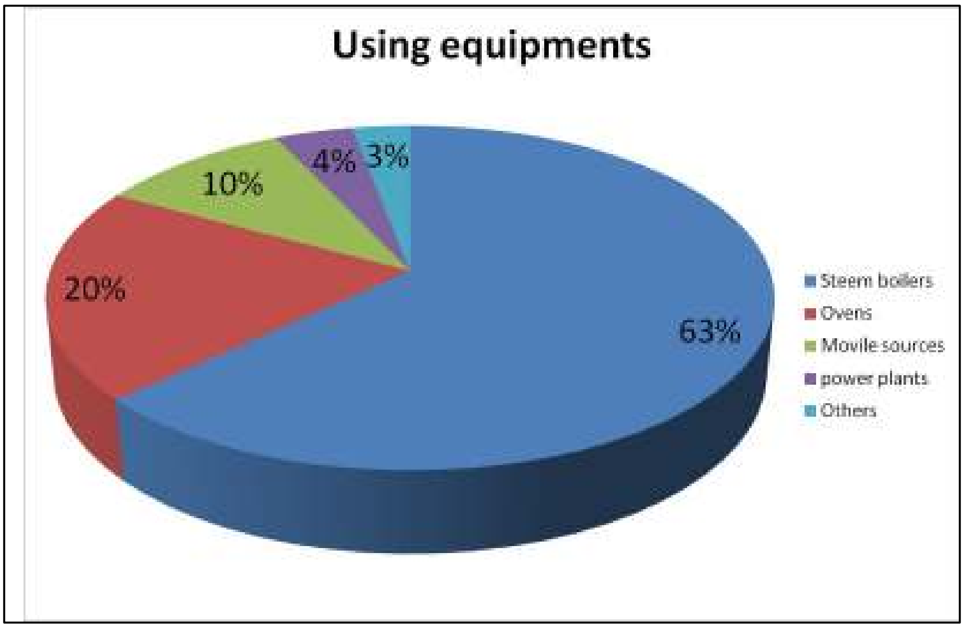
There are several type of industries located throughout Medellin- Bogota highway as major development axel due to the convenience it presents to transport all produced goods to the entire country and overseas. We can count between this industries textile, food processing, metalworking, paper, among others that use all kinds of fuels available in the country.
Fuel use is describe below:



*source: EPM – Cornare

In this graphic it´s evident the extended use of fossil fuels in the industry, and most common use of coal due to the low price and availability since Antioquia has a major coal mine not far from Medellin.

The equipment that use the most amount of fuel are boilers to produce heat and water vapor for diverse means such as dying, heating, melting, etc.



*source: EPM – Cornare

Objectives

- Analyze PM, NOx, SO_2, CO_2 emissions to the atmosphere generated by coal, LPG, waste oil and wood combustion in industrial boilers. Compare the level of emissions with Colombian regulations and EPA´s emission factors.
- Try to make a preliminary estimation of the possible impact generated by industrial boilers emissions by using a numerical dispersion model implemented in another region of Colombia. Estimate a possible impact to the nearest community location.
- Promote the reduction of CO2, PM, SOx and NOx released by boilers in affiliated industries, by implementing good practices and operational control, and using BAT if possible. Document in a best operational control procedure for industrial boilers.

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4. Methodology

Methodology used comprises bibliographic search, interviews, data collection and analysis.

Data collection required the elaboration of a survey to gather all necessary information on all 4 industries regarding source of emission, it was taken from a classmate of the APM training program and modified to fit this study.

AIR POLLUTION EMMISION QUESTIONNAIRE

Date	
Evaluator	
Company´s Contact person	
Company name	
Company address / Municipality	
Utm's or latitude/longitude of stack	
Permit number	
Pollutants tested:	
Emission concentration (mg/m^3)	
Flux Emission rate (kg/h)	
Date installed/modified	
Model No.	
Boiler capacity	
Fuel(s) use	
Heat input (Mmbtu/hr)	
Fuel quality analysis	
Calorific power	
Feeding of fuel	
Monthly consumption	
Efficiency	
Stack height above ground (m)	
Stack internal diameter	
Does stack have a rain cap or is discharge horizontal	
Stack internal diameter (i.d.) (m) & flow	
Stack temperature (deg. C)	
Stack velocity (m/s)	
Distance from stack to nearest plant boundary (m)	

To protect and respect the identity of industries that has participated in this study, they have been identified by numbers depending on fuel type as follows:

Fuel type: wood scrap, bark Industry 1 - I1-
Fuel type: Liquefied Petroleum Gas LPG – Industry 2 – I2-

Fuel type: coal – Industry 3 - I3 -
Fuel type: waste oil /industrial oil, industry 4- I4-

For starters, Colombian legislation on atmospheric emission from stationary sources was analyzed, mainly for external combustion equipment. The standard actually in force only (Decreto 02/1982) requires stack altitude of 15 meters above ground level and 5000 ppm of PM. However, starting July 15th 2008 a new standard was emitted in Colombia that sets more restricted emissions limit values for a wider range of industries types and a wider range of pollutants but it is only in force starting July 15th 2010. Thus, this is the standard that it is going to be taken in consideration for all necessary calculations and analysis for the industrial boilers emission, presented as mg/m^3.

Resolution 909/2008, establishes regulations and standards regarding some pollutants levels, depending on the type of fuel used in stationary source and type of production process. (Article 7)

Table 1. Resolution 909 pollutants levels

Fuel type/external combustion equipment	Pollutant /EQS Limit value (mg/m^3)		
	PM	SO2	NOx
Solid	200	500	350
Liquid	200	500	350
Gaseous	NM	NM	350

NM: stands for “not mandatory”

For external combustion equipment that uses biomass as fuel, there is a different emission quality standards (EQS) levels: (article 18)

Table2. EQS for biomass boilers

Fuel type/external combustion equipment	Pollutant /EQS Limit value (mg/m^3)	
	PM	NOx
Biomass	300	350

In addition to these EQS levels it is mandatory to have operational controls such us humidity weight in percentage of the biomass, temperature of stack gases and calorific power of biomass (dry base). (Article20)

The EPA´s emission factor where also identified and analyzed presented as AP 42 publication. This data was only taken as reference to establish a quantitative point of comparison on emission levels and type of technology used in the United States and in Colombia so I could have references of best operational practices for studied boilers.

An emissions factor is a representative value that attempts to relate the quantity of certain pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average).

Table 3. EPA´s AP 42, Volume I, Fifth Edition

Bark and wet wood with no control device			
PM (lb/mmBTU)	NOx (lb/mmBTU)	SO2 (lb/mmBTU) EFR=A	CO_2 (lb/mmBTU) EFR=A
0,56	0,22	0,03	195

LPG commercial use propane			
PM (lb/103 gal)	NOx (lb/103 gal)	SO2 (lb/103 gal)	CO2 (lb/103 gal)
0,7	13	0,108	12500

Bituminous Coal - spread stoker with cyclone			
PM (lb/ton)	NOx (lb/ton)	SO2 (lb/ton)	CO2 (lb/ton)
12	11	28,12	4810

Waste oil or No. 6 (residual) fuel oils			
PM (lb/103 gal)	SO2 (lb/103 gal)	NOx (lb/103 gal)	CO2 (lb/103 gal)
49,28	135,24	19	22000

The units conversion of Emission Factors (EF) given in (lb/Mmbtu or lb/ton of fuel) which are different than the ones used in Colombian regulation (mg/m3) was made using the following survey data:

- Calorific Power of Fuel (data from lab analysis or supplier
- Monthly fuel consumption
- Heat input
- Pollutant Load (kg/h)
- Pollutant Flow (m^3/h)

Table 4. EPA Emission factors found for related equipment and fuels in (mg/m^3)

Bark and wet wood with no control device		
PM mg/m^3	NOx mg/m^3	SO_2 mg/m^3

87,7	34,5	3,9

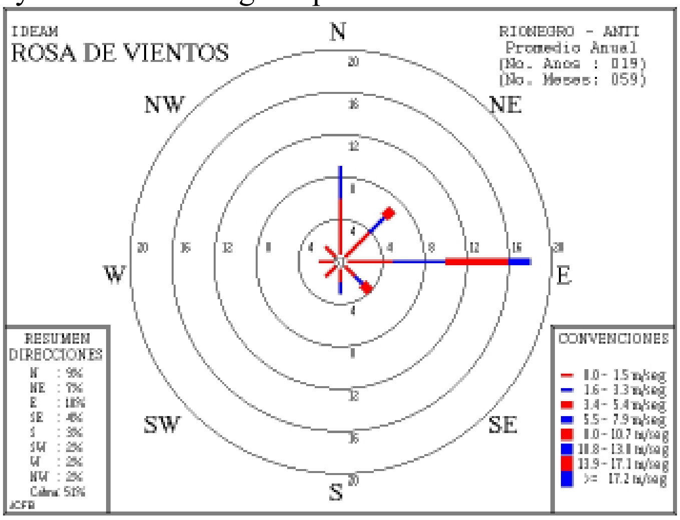
LPG commercial use propane		
PM mg/m^3	NOx mg/m^3	SO_2 mg/m^3
8,7	161	1,3

Bituminous Coal - spread stoker with cyclone		
PM mg/m^3	NOx mg/m^3	SO_2 mg/m^3
272,4	250	638

Waste oil combustion Small boilers		
PM mg/m^3	NOx mg/m^3	SO_2 mg/m^3
182,9	70,5	502

The resulting data of this analysis, aiming to conclude about the possible impact on community, come from dispersion simulations within the AIRVIRO air quality management system implemented by CVC in Valle de Cauca. Although meteorological conditions may differ between Valle de Cauca and Antioquia, the simulations will give some ideas about a likely impact of the emissions generated by this type of industrial boilers.

The nearest meteorological station is located at the international Airport, located at close range of industries and it is the only one available, so it has to be used. Data is provided by the Colombian meteorological institute (IDEAM). The Wind rose shows that the predominant wind direction is east with 18% of occurrence and most of the time is calmed (51% occurrence). Wind speed is not higher than 7,9 m/s. It should be noted that 51% of zero wind speed is a sign of poor measurement technology (high threshold). The quality of the data is not sufficient as input to dispersion models, for which low wind speeds often are the most important input as they are related to high impact close to emission sources.



5. Results

5.1. Industry # 1 – Fuel: Bark and wet Wood

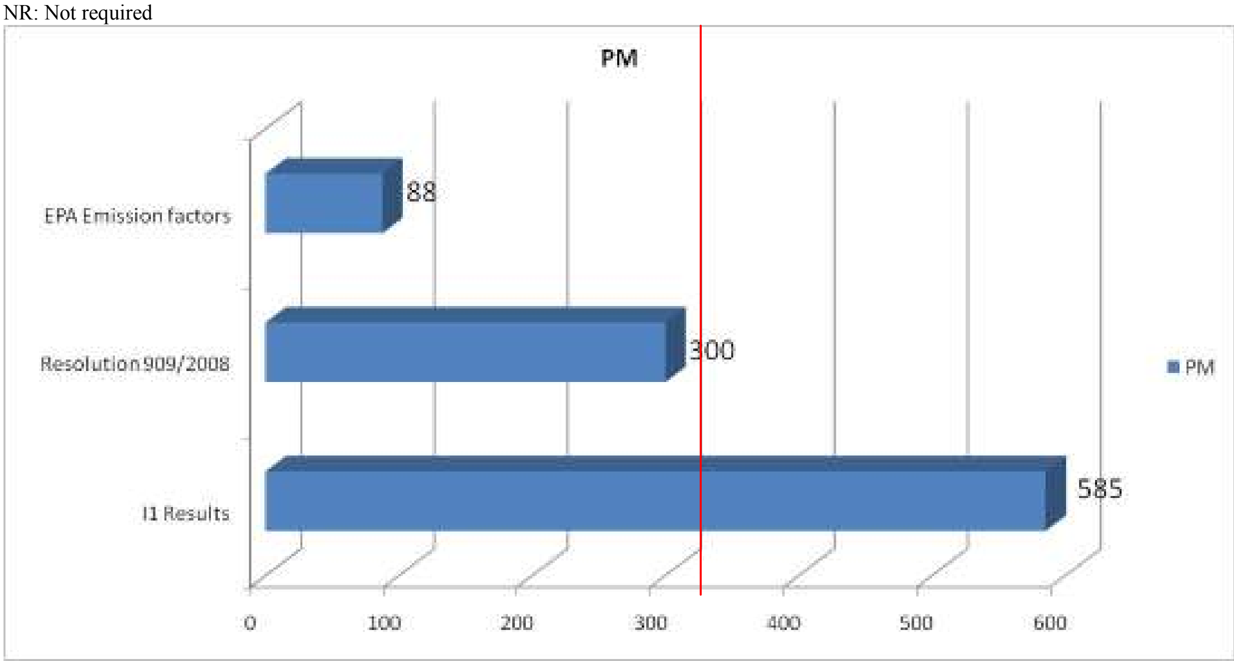
According to the last stack sampling made in 2007, PM emission concentration is 585,29 mg/m^3, exceeding Colombian standard of 300 mg/m^3 (about 95% above).

NOx emissions are not available since it was not required by law at the time of stack monitoring.

Table 5. Results for bark and wet wood boiler

Pollutant	I1 Results	Resolution 909/2008	EPA Emission Factors
PM	585	300	88
NOx	NA	350	35
SO_2	NA	NR	3,9

NA: not available
NR: Not required



Source: AP 42, Fifth Edition Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources. US EPA

Possible causes of high pollutant emission

These emissions depend basically of the composition of burned fuel and the particulate emission control device, and since they do not have one, PM emissions are higher.

Nitrogen Oxides NOx can also be emitted in significant amounts when certain types of Wood residue are burned or when operational practices are poor.

The following factors can affect emissions performance in boilers:

- Boiler design
- Combustion control
- Boiler size and load fluctuations
- Fuel parameters such as humidity (if possible under 50%), fuel type (for example Wood chips or Wood pellets) fuel size, bark content and wood type
- Boiler optimization
- Boiler maintenance
- Operator experience and automatization of operational control
- Use of Pollution control devices

By weight difference and by hygrometer measurement to the wood, it has been identified a wood moisture content between 90-130%. By laboratory analysis, made on November the 24th this wood shows residual moisture of 17.8%.

The wood must be released, as much as possible, from moisture content so it can offer the higher levels of calorific value as possible. To achieve this, is important to allow complete drying periods and good conditions to the storage method.

We recommend storing the wood indoors and in pieces of uniform size.
When wood has high moisture content:

- Reduced calorific power
- Hampers ignition
- Its combustion produces condensation and tar in the flue

It has been proven that in real cases where Wood with more tan 50% of humidity content, has a calorific power of 3 Kw/Kg, but this humidity content is reduced to 15%, the calorific power goes up to 4.6 Kw/kg.

The furnace operating conditions are particularly important when the fuel is wood. For example, due to the high content of moisture present in wood, it would require a larger than usual refractory area to dry the fuel before combustion. Additionally, it needs to provide sufficient secondary air on the bed of fuel to burn the volatiles, responsible for most of the combustible material in wood bark. When you do not have appropriate drying conditions or when secondary combustion is incomplete, the combustion temperature goes down and particulate matter, CO, and emissions of organic compounds increases. Significant variations in fuel moisture content can cause fluctuations in short-term emissions

Possible solutions - recommendations

To achieve the permitted standard of 300 mg/m^3 a system of cyclones and fabric filters should be implemented as particulate matter control system in the boiler´s stack, but it is also necessary to evaluate the possibility of reducing the moisture content of wood before feeding it to the combustion chamber. It is also recommended to hire expert support to determine the best maintenance practices for this specific type of boilers in order to reduce NOX emissions.

Investments for PM emission control is around USD$50.000

I1 – Estimation of possible human health impact of I1 Emissions

The nearest residential area is found about 180 m from the stack. At that distance the I1 emissions are likely to generate a contribution to annual average PM10 concentration below 1 μg/m3.

5.2. Industry #2 – Fuel: Liquefied Petroleum Gas LPG

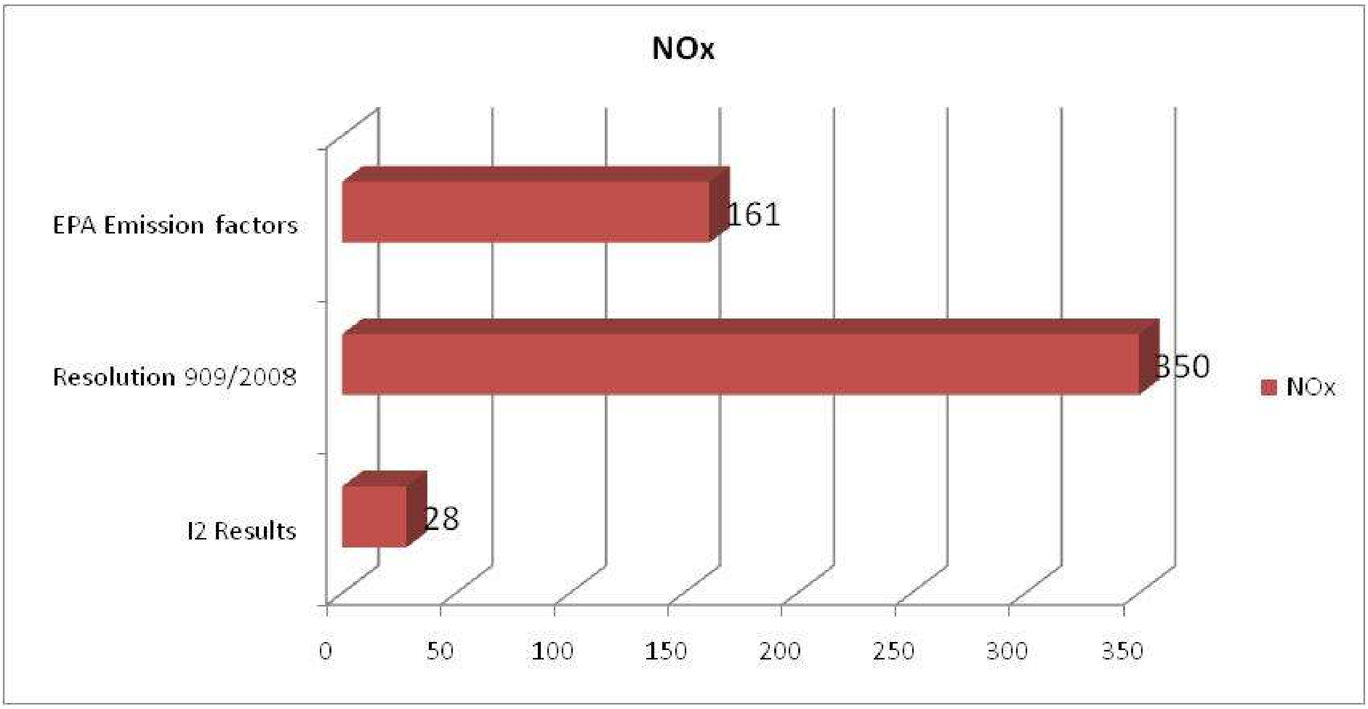
The results of particulate matter and nitrogen oxides (NOx) from stack sampling in October 2008 are shown below

Table 6. Emission results for LPG boiler

Pollutant	I2 Results	Resolution 909/2008	EPA Emission Factors
PM	18	NR	9
NOx	28	350	161
SO2	NA	NR	1,3

Colombian legislation has no emission standard for PM when LPG is used as fuel. From results it can be concluded that I2 complies largely with NOx emission limit values established by Resolution 909/200.

As for EPA PM Emission factors it can be said that I2 exceeds this emission factor, this may be due to the quality of fuel used in the country. Later 2009, I2 converted LPG to natural gas supply, but no stack sampling has be done to compare to national standards, however it can be expected I2 complies with it as well.



Recommendations
Keep up with regular maintenance to boiler and fuel feeding system

I2 - Estimation of possible human health impact of I2 Emissions

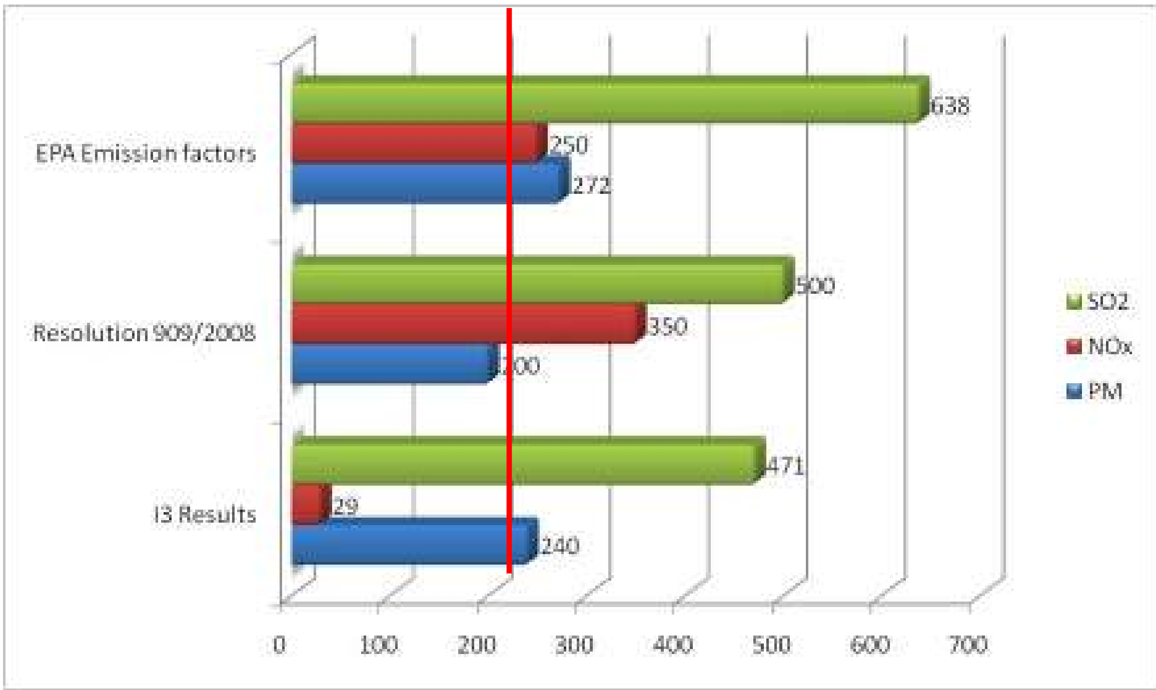
The nearest residential area is found 110 m from the stack and we can expect that I1 emissions are likely to generate a very small contribution to annual average PM10 concentration, of the order of 0,1-0,2 $\mu g/m^3$.

5.3. Industry #3 – Fuel Bituminous Coal

The results of particulate matter, sulfur oxides (as SO2) and nitrogen oxides (NOx) from stack sampling in December 2008 are shown below

Table 7. Results for coal boiler

Pollutant	I3 Results	Resolution 909/2008	EPA Emission Factors
PM	240	200	272
NOx	29	350	250
SO2	471	500	638



PM concentrations exceed Colombian standards by 20% although they are below EPA´s emission factors.

I3 boiler complies with SO2 and NOx emissions levels; this last one for over 92%, due to regular maintenance made to the equipment and that the boiler is relatively new (form 2005)

Recommendations
Uncontrolled PM emissions from coal-fired boilers include the ash from combustion of the fuel as well as unburned carbon resulting from incomplete combustion.

The principal control techniques [1]for PM are combustion modifications and postcombustion methods. Uncontrolled PM emissions from small and hand-feed combustion sources can be minimized by employing good combustion practices such as operating within the recommended load ranges, controlling the rate of load changes, and ensuring steady, uniform fuel feed. Proper design and operation of the combustion air delivery systems can also

[1] Source: AP42

minimize PM emissions. The postcombustion control of PM emissions can be accomplished by using, besides the actual cyclone, multicyclone collector or a Fabric filter (or baghouse)

I3 - Estimation of possible human health impact of I3 Emissions

The distance from I3 emission source to the first residential unit exceeds 400 meters west, where a contribution to the annual average concentration of PM10 should be below 0,5 µg/m^3.

5.4. Industry I4 – fuel: Waste oil

Waste oil [2]includes used crankcase oils from automobiles and trucks, used industrial lubricating oils (such as metal working oils), and other used industrial oils (such as heat transfer fluids). When discarded, these oils become waste oils due to a breakdown of physical properties and contamination by the materials they come in contact with. The different types of waste oils may be burned as mixtures or as single fuels where supplies allow.

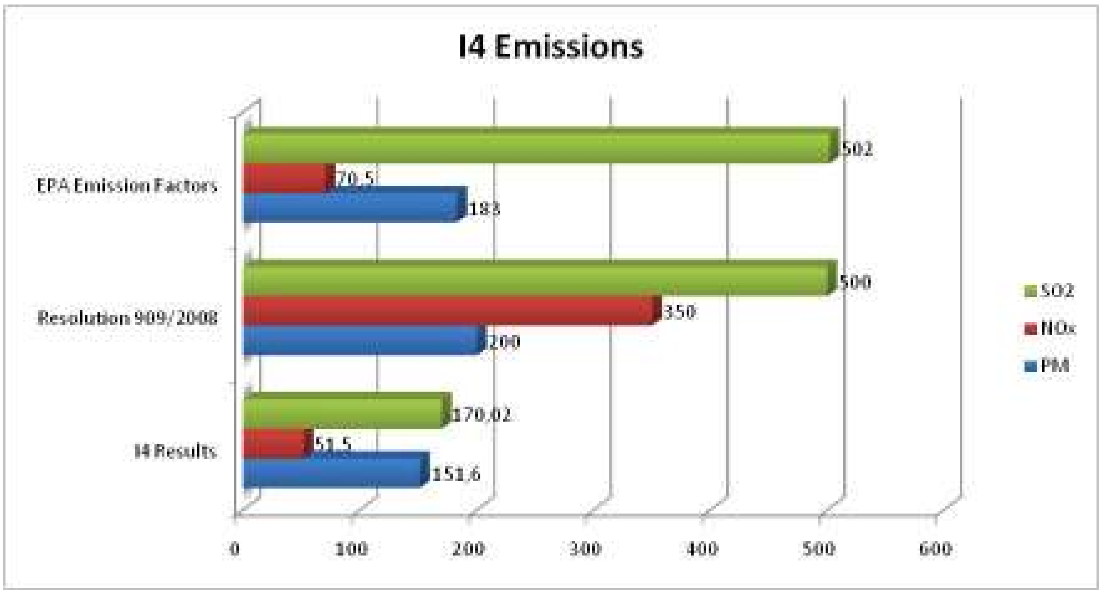
The type of waste oil used by I4 comes from the recovery of used lubricating oil, after going through filtration, distillation and addition of additives process to improve its calorific value. The results of the analysis of this fuel type are shown below:

Analysis	Units	Results
Distillation water	%vol	0,5
Ashes	%P/P	0,77
Sulfur content	%P/P	0,92
Calorific power	KJ/kg	43657
Flammability point	˚C	73
Carbonaceous residue	%P/P	5,6

The results of particulate matter, sulfur oxides (as SO2) and nitrogen oxides (NOx) from stack sampling in December 2008 are shown below

Table 8. Results for waste oil boiler

Pollutant	I4 Results	Resolution 909/2008	EPA Emission Factors
PM	151,6	200	183
NOx	51,5	350	70,5
SO_2	170,02	500	502



[2] Source: AP42 chapter 1.11 Waste oil combustion

I4 complies with all levels of pollutant emission both Resolution 909/2008 and EPA emission factors. To highlight, the level of nitrogen oxide emission which is 92% below the national standard, maybe due to good operational practices, periodic maintenance plan and relatively new equipment.

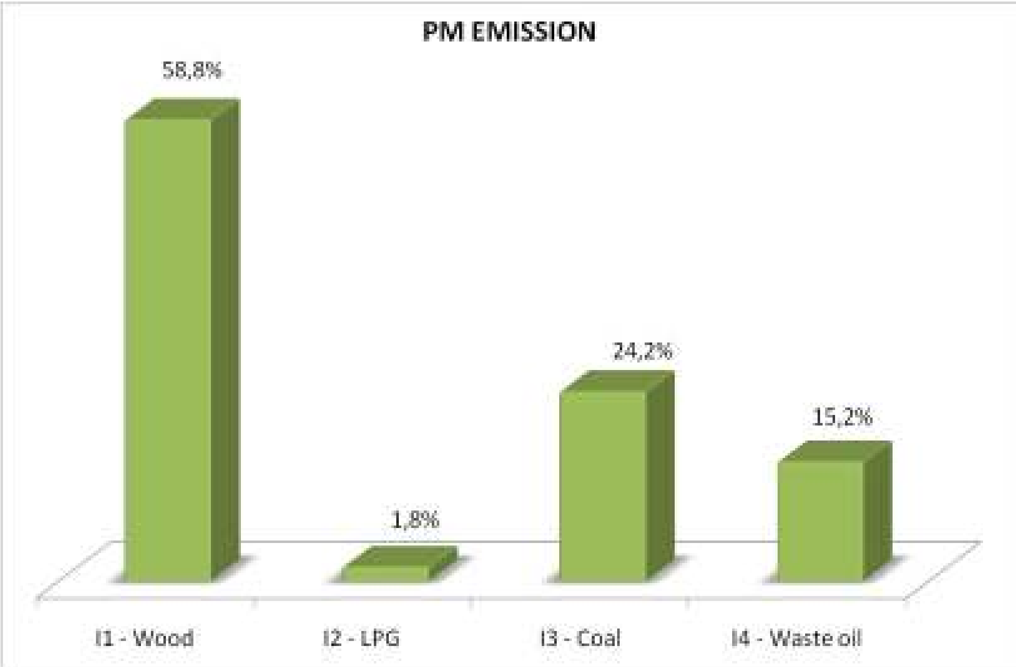
I4 – Estimation of possible human health impact of I4 emissions

The distance from I4 emission source to the first residential unit exceeds 180 meters northeast, where a contribution to PM10 annual average levels is likely to be below 0,5 $\mu g/m^3$.

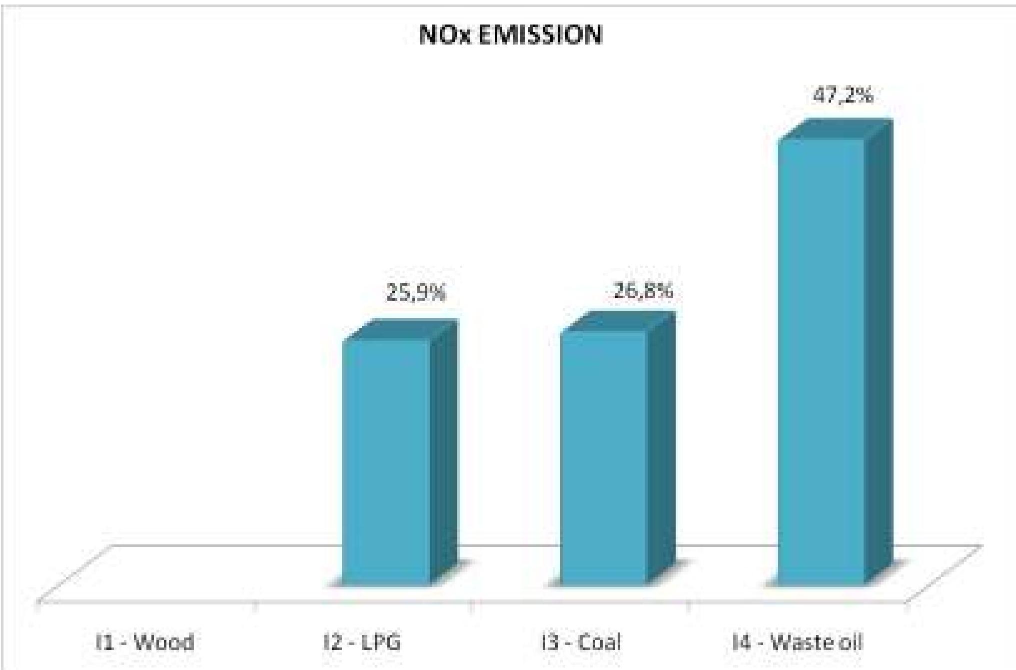
5.5. Overall results

The following is a summary comparison of the emissions of four industries evaluated

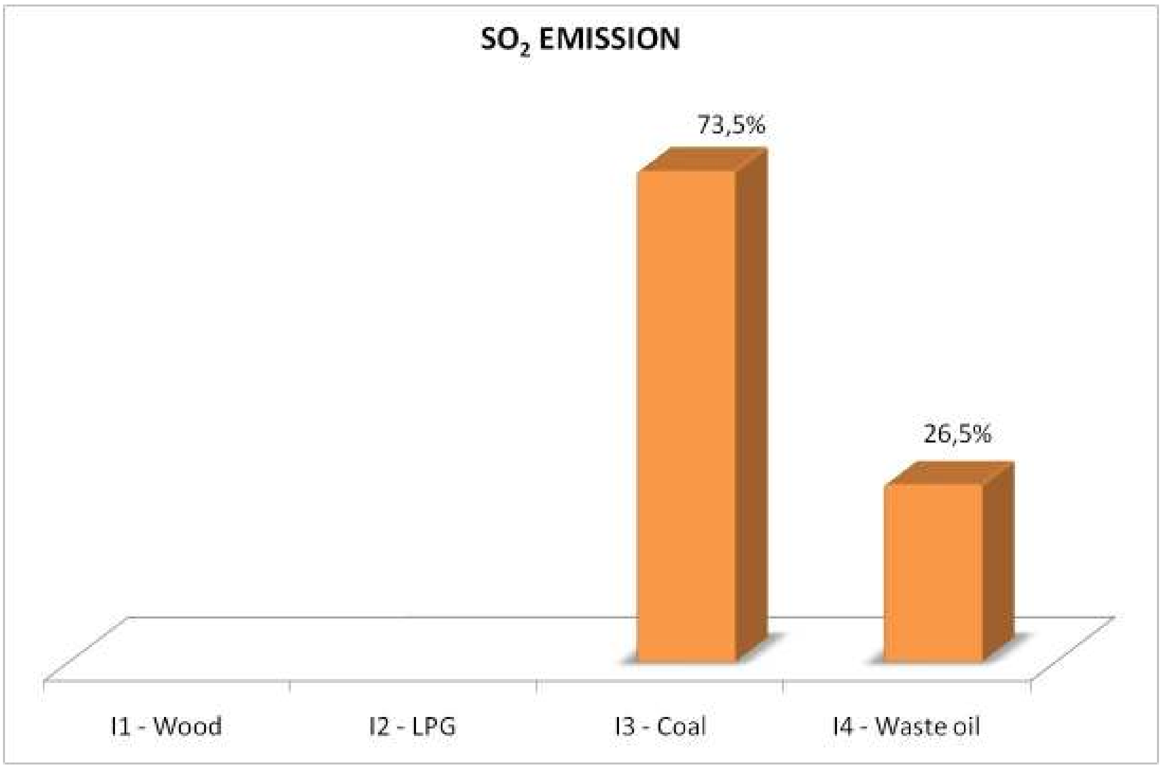
1- PM: highest value is presented by I1 – Wood bark with 585 mg/m^3 of PM, followed by I3 – Coal with 240 mg/m^3 of PM emission, both exceed Colombian legislation. Follow graph shows the percentage of each industry's contribution to emissions of particulate matter



2- NOx: highest value is presented by I4 – waste oil with 51,55 mg/m^3 of NOx followed by I3 – Coal with 29,3 mg/m^3 of NOx, however none of them exceed the national standard. Follow graph shows the percentage of each industry's contribution to emissions of NOx



3- SO_2: from the values obtained by the industries 3 and 4, the highest one is presented by I3– coal with 471 mg/m3 of SO2 emissions, follow by I4 – waste oil with 170 mg/m^3 of SO2; however none of them exceed national standard. Follow graph shows the percentage of each industry's contribution to emissions of SO_2



5.6. CO2 emissions

I1 - CO2 Emission

Stoichiometricly is possible to calculate the quantity of products obtained on a given base of fuel (eg, 100 kg). Thus, for the case of wood, according to laboratory tests done in December 2009, wood used as fuel is composed by 88% of volatile C,

Stoichiometric Equation C + O2 → CO2

Base for calculations	= 100 kg of wood
C quantity	= 88 kg
CO2 quantity produced	= (88 kg C/100 kg wood)*(44 kg CO2 / 12 kg C)
	= 3,2 kg CO_2/ kg wood
	=0,0002 kg CO2/ KJ in terms of energy units,
	And multiplied by wood consumption
	= 974,5 kg CO_2/hour

I2- CO2 emission

For Colombian fuels, the national Ministry of Mines and Energy has calculated the emission factors

Table 9. CO_2 emission factor by fuel (kg/GJ)

Fuel	Emission Factor (kg CO_2/GJ)[b]
LPG	63.02

a. **Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual** IPCC. Bracknell, U.K.
b. Calculated from C + O_2 → CO_2

The estimated emission for I2 is 279,2 kg CO2/hour

I3. CO2 Emission

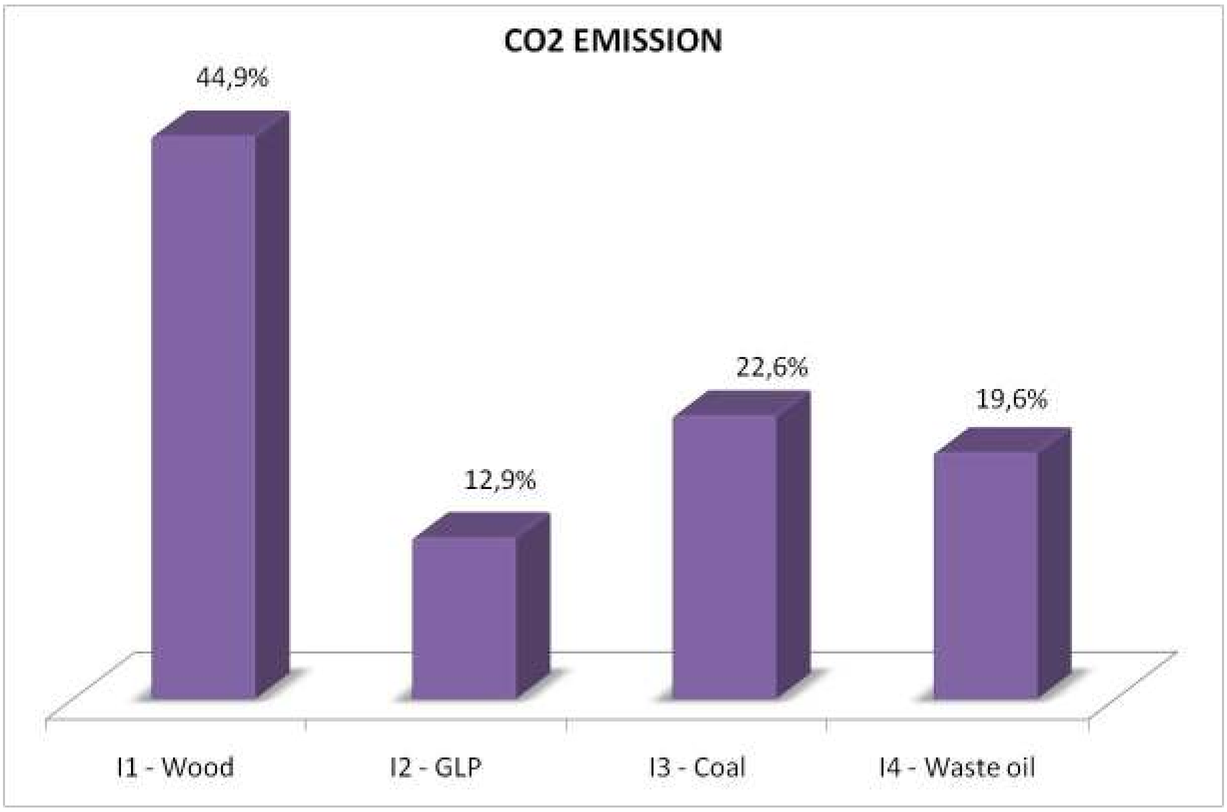
Fuel	Emission Factor (kg CO_2/GJ)[b]
Coal	94.53

Taking as reference the emission factor given for Colombia multiplied by monthly fuel consumption, the estimated emission for I3 is 490,5 kg/hour

I4. CO2 Emission

Fuel	Emission Factor (kg CO_2/GJ)[b]
Fuel oil	74,01

Taking as reference the emission factor given for Colombia multiplied by monthly fuel consumption, the estimated emission for I3 is 426,3 kg/hour


CO2 EMISSION
44,9%
12,9%
22,6%
19,6%
I1 - Wood
I2 - GLP
I3 - Coal
I4 - Waste oil

6. Conclusions

This brief analysis served to demonstrate to Industry 1 and 3 the need to implement mitigation measures of PM emitted by their boilers. Not only because of the implications that brings non-compliance of Resolution 909/2008 but also the potential impact their emissions can have on surrounding community, because if not controlled, may be greater in the future.

While biomass has enormous potential in replacing fossil fuels such as coal, for its availability and low price, this type of fuel has as well major impacts on air pollution in terms of emissions of PM and NOx. Fortunately this negative impact can be effectively mitigated with the use of controls devices on boilers or controls over fuel characteristics, a fact clearly demonstrated by the low emission factors that EPA gives for these devices.

All those emissions that presented low levels of air pollutants according to Resolution 909/2008 and EPA´s EF, are those produced from combustion of Gaseous fuels as well as the use of equipment with new and better technology. This is an aspect that should be evaluated by industries whose emissions are above the national standards, for what they only have 3 months (until 15 July 2010)

It is necessary that the environmental authority strengthens the requirements for industries to performance periodic stack sampling, as well as industries do it for operational control.

Environmental authority should have a more accurate air quality monitoring system in eastern Antioquia, since the last one is from 2005, could be that the inmission levels have raised in the past 4 years due to higher vehicular flow and more industries settlement in this period of time.

7. The way forward

The results of this study will be disseminated to all managers in 74 affiliated industries to create consciousness on the importance of controlling atmospheric emissions and most of all on legislation compliance at all times.

Among them environmental authority, try and encourage them to implement definitive measures to monitoring and controlling air quality in this region throughout the establishment of stations in critical points aiming to protect and prevent air quality decrease.

It is necessary to continue sharing the knowledge acquired in this training program with affiliated industries through periodic workshops where atmospheric pollution processes can be discuss as well as implementation of good operational controls or new technologies to prevent deterioration of air quality due to industrial processes.

8. Acknowledgements

First of all I would like to thank Doctor Lars Gidhagen who was my contact person, for his support during the entire training program. I was very fortunate to have him by my side in these project.

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