Comparative Study of Poluttant Emissions from the Fossil Fuel Power Plant and Influence Upon Urban Air Quality in Timisoara

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In this article, the authors propose a comparative analysis of air quality in urban area of Timisoara before and after retrofitting of the local power plant, with the goal to identify the level of human discomfort. The air quality analysis was based on on line measurements consisting of legally attested equipment that was set up to monitor fine particulate matter, nitric oxides NO, NO_2, carbon monoxide CO, sulphur dioxide SO_2, and, as well as wind speed and direction. Emission data collected during 2 years, in 2012 and 2014 before and after retrofitting, referring to maximum 24-hour concentrations and the occurrence of exceedances over the limit values are comparatively analyzed. The relative investigation presents the evolution for the concentration of the most important pollutants involved in the atmospheric pollution process. Finally, in addition to measures already achieved for retrofitting and declared effective by the comparative analysis, one also proposed supplementary pollutants control technologies on coal fired boilers in response to new requirements of air quality, as well state of art for the pollutant emissions.

Keywords: urban area, air pollution, district heating

Air pollution has negative effects on human health and the environment, and involves additional costs on the population, others than those generated by another pollutants.

Current policies aim either to regulate the level of pollutant emissions at the source or to increase the private cost of polluting. It is worth to mention that air quality is hardly influenced also by natural causes: erupt volcanoes, windblown dust, emissions of volatile organic compounds from plants. Air pollution is achieved also due to human action: combustion of fossil fuels to benefit as result of energy in form of electricity, heat, running transport, industry, chemical industry and mining, agriculture, sewage treatment.

For European countries, the National Emission Ceilings Directive (NEC Directive) sets out the main pollutant emissions at source.

Internationally the amount of pollutants is regulated by UNECE Convention on Long-range Trans boundary Air on Pollution and Its Protocols. The Gothenburg 'multi-pollutant' protocol was approved in 2012 and includes contaminant level required for 2020 and introduces a maximum level for PM2.5 [1].

One of the main pollutants are nitrogen oxides, obtained largely from burning fossil fuels in large combustion plants and can be formed by three mechanisms figure 1.

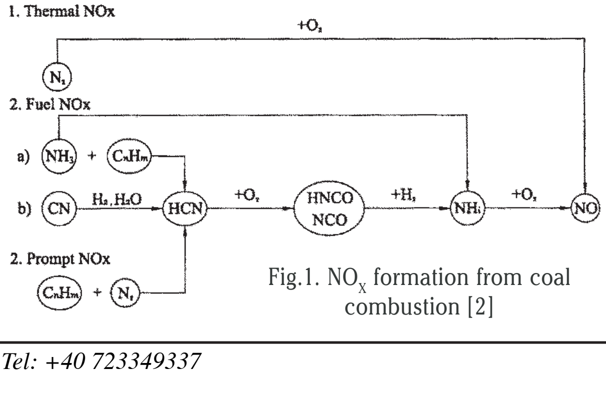

Fig.1. NO_X formation from coal combustion [2]

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The main nitrogen oxides produced by combustion are NO and NO_2; they are grouped under the name of NO_X. The main sources of NO_X are electricity production in large combustion plants with a share of over 54%, road transport with a share of 36%, and the remaining 10% is divided between other modes of transport and industry, including individual combustion facilities.

Figure 2 presents the average annual values of nitrogen oxides measured until 2010 and imposed level of NO_X to our country of 170 Gg to be achieved until 2020. Romania presently has an average of 230 Gg, beyond the requirements for 2016 of 200 Gg. In order to meet conditions imposed for 2020 one needs a reduction of the NO_X emissions by 30% nationwide (fig. 2).

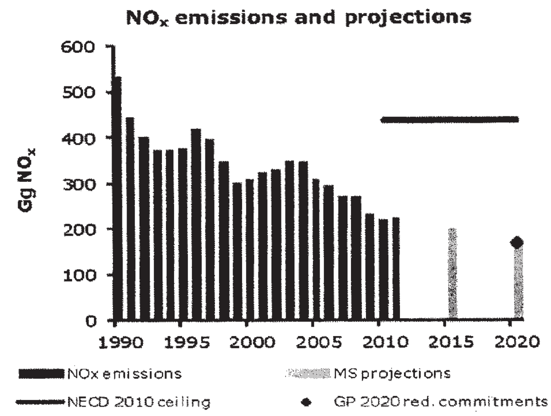

Fig.2. NO_X emissions and projections for Romania [1]

Another pollutant that is monitored and has a negative influence on the environment and human health is SO_2. It is generally obtained by oxidation of sulfur during burning fuels containing sulfur. The main sources of sulfur oxides are large combustion power plants with a share of 99% and the rest of 1% is generated by other industries.

At 800°C and in the presence of vanadium of iron oxides SO_2 convert to SO_3 and it is known as high temperature corrosion. Under the presence of ultraviolet radiation SO_2 reacts with oxygen and forms O_3 [7].

$$2SO_2 + O_2 + uvr = 2SO_3 \qquad (R1)$$

In the atmosphere, SO_3 reacts with the water vapors to form H_2SO_4. In periods with high humidity the transformation rate of SO_2 to H_2SO_4 can reach up to 15% [8].

$$SO_3 + H_2O = H_2SO_4 \qquad (R2)$$

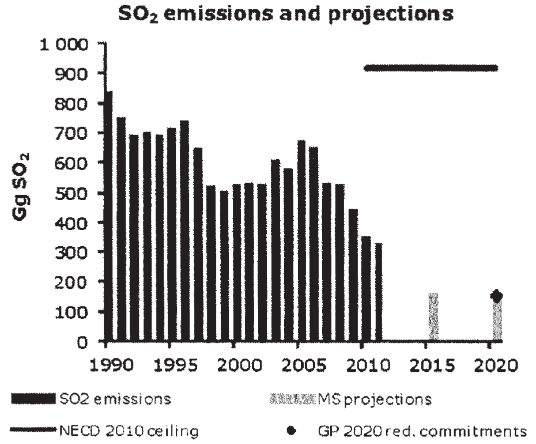

Fig.3. SO_2 emissions and projections for Romania [1]

In figure 3 are shown the average annual values for sulfur oxides measured until 2010 and the imposed SO_2 levels to our country of 155 Gg by 2020. Romania presently has an average of 350 Gg, beyond the requirements for 2016 of 330 Gg. In order to meet conditions imposed for 2020 we need to reduce emissions of SO_2 over 50% nationwide.

Carbon oxides are obtained because of the incomplete burning.

Combustion and it is the main greenhouse gas with a share of 77% of total anthropogenic greenhouse gas emission [9]. The main sources are electricity production in large combustion plants with a share of over 80%, road transport with a percentage 16%, and the remaining 4% is divided between other modes of transport and industry.

Relations R3-R10 indicates the simplified chemical equations in the process of gasification of solid hydrocarbons [10]:

$$C + 1/2\,O_2 = CO + q \qquad (R3)$$
$$C + O_2 = CO_2 + q \qquad (R4)$$
$$C + 2H_2O = CO_2 + 2H_2 - q \qquad (R5)$$
$$C + H_2O = CO + H_2 - q \qquad (R6)$$
$$C + 2H_2 = CH_4 + q \qquad (R7)$$
$$CO + H_2\text{-}O = CO_2 + H_2 + q \qquad (R8)$$
$$CO + 3H_3 = CH_4 + H_2O + q \qquad (R9)$$
$$C + CO_2 = 2CO - q \qquad (R10)$$

Figure 4 shows the average annual values of carbon oxides measured until 2010. The level of CO was not imposed following these directives and protocols. Romania presently has an average of 1000 Gg.

PM is a mix between aerosol particles (solid and liquid). PM_{10} or $PM_{2.5}$ are particles with a diameter of 10 microns or 2.5 microns. PM is produced directly and spread into the atmosphere or is produced by other pollutants such as SO_2, NO_x, NH_3 or non-methane volatile Organic Compounds (NMVOCs).

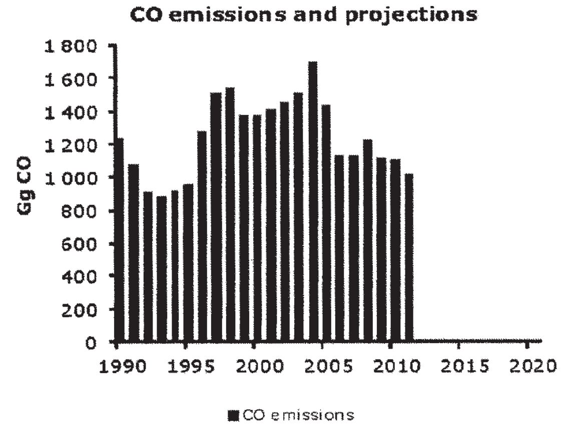

Fig.4. CO emissions and projections for Romania [1]

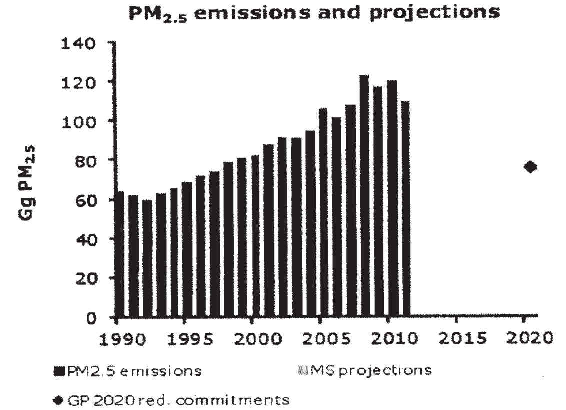

Fig.5. PM2.5 emissions and projections for Romania [2]

In figure 5 are shown the average annual $PM_{2.5}$ values measured by 2010 and the imposed $PM_{2.5}$ levels to our country of 76 Gg by 2020. Romania presently has an average of 109 Gg in order to meet conditions imposed for 2020 we need a $PM_{2.5}$ emission reduction of over 30% nationwide.

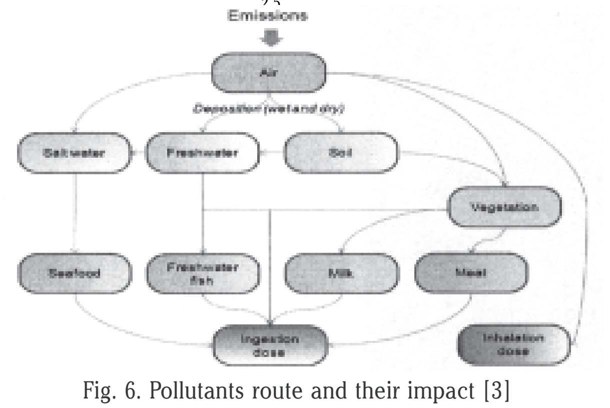

Fig. 6. Pollutants route and their impact [3]

Air pollutants are a complex issue; they interact in the atmosphere and harm human health, ecosystems and climate (fig. 6) [3].

In recent years actions taken resulted in a decrease in the emission level. Presently, pollutant concentrations are over the limit and have a negative effect on health and the ecosystem in which we live. Most problems occur in areas that are urban agglomerations, cities, where all major sources of generating NO_X are active.

Available technologies for reducing pollutants can be included [17]:

-removing or reducing pollution from the source, from coal before it is burned;

-reduction of pollutants during combustion;

-reducing pollutants in the flue gas on their way to chimney.

Modern installations are capable to reduce significantly pollutants emissions from coal fired power plants[6]:

- scrubbers installed in the 80 had the level of reduction around 80-90%. Their innovations have yielded a 98% reduction;

-NO_X emission can be reduced with more than 90% using a SCR installation;

- using a baghouse system on coal fired power plants, removal of mercury and other hevy metals can be reduced with more than 90%.

Experimental part

Timisoara has the same moderate continental climate, as part of Timis County. Its general features are marked by diversity and irregularity of atmospheric processes. Frequently, even in winter, arriving moist air masses from the Atlantic, bringing rain and snow significant, less cold waves.

The most common, for Timisoara in 2012 before the refurbishment of multi data are Eastern winds (11.2%) and West winds(6.9%) [4].

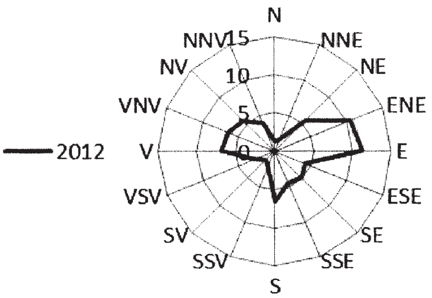

Fig. 7. Wind rose by 2012 at Timisoara [4]

The most common situation, for Timisoara by 2014, from the multiannual data is the presence of the West winds (18.3%) and Northwest ones (8.5%). Wind rose was simulated using the program WRPLOT View Environmental Lakes V3.5 product. The input data were taken from the database of [5].

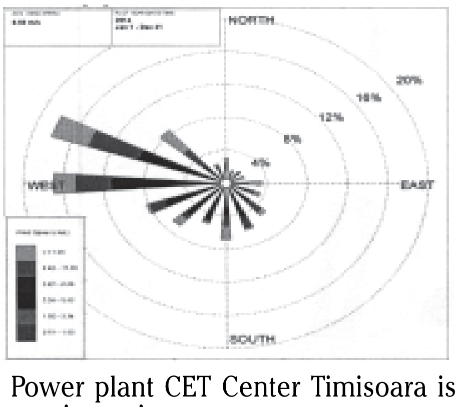

Fig. 8. Wind direction frequency by 2014 in Timisoara

Power plant CET Center Timisoara is composed of the main equipment:

-two hot water boilers of 50 Gcal/h (58.15 MWt) powered by natural gas called CAF 1, CAF 2;

-three hot water boilers of 100 Gcal/h (116.3 MWt) powered by natural gas called CAF 3, CAF 4, CAF 5;

-three steam boilers of 30 t/h, 35 bar, 450 ° C powered by natural gas and crude oil called CAE1, CAE2, CAE3;

-a steam turbine type AKTP 4 to 3 bar backpressure and 3 MWe;

-one plate heat exchanger for district heating capacity of 18.5 Gcal/h (21.15 MWt).

According to the state of art knowledge and best practice indication in the EC, retrofitting of CET SUD Timisoara power plant running coal, in order to meet all environmental conditions, consisted in implementation of:

- installation of flue gas desulphurization (FGD);

- installations for NO_X removal, Selective non-catalytic reduction (SNCR), low NO_X burners and over fire air ports (OAP);

- construction of dense slurry station to solve the problems of ash deposit and reduce the pollution with PM.

The operating principle of dry FGD

The flue gases from the steam boiler units CA1, CA2 & CA3 with a temperature of 150 - 160 °C is collected by a common raw gas system and led to the lower part of the Circulating Dry Scrubber (Absorber) (see Figure 9). In order to raise the reactivity, the flue gas is cooled down to the operation temperature of about 75 °C by water injection. In the Absorber the flue gas gets into contact with the sorbent and recirculated product from the fabric filter and leaves the Absorber at the top. Immediately after the Absorber the flue gases enter the fabric filter where dust and reacted / remaining sorbent will be removed.

A FGD flue gas fan must be installed downstream of the fabric filter. The fan will be controlled by the use of a frequency converter and shall be able to compensate the pressure loss caused within the FGD plant and the complete flue gas path downstream of the existing ID-fans. After the FGD flue gas fan the flue gas duct is led to the existing stack for discharge.

The following reactions (R11-R17) are essential for the dry desulphurisation process in the temperature range between 70°C and 100°C (the given formulae are cumulative formulae and do not reflect the true course of the reactions in individual steps):

$$Ca(OH)_2 + SO_2 = CaSO_3 * 1/2\, H_2O + 1/2\, H_2O \quad (R11)$$
$$Ca(OH)_2 + SO_3 = CaSO_4 * 1/2\, H_2O + 1/2\, H_2O \quad (R12)$$
$$Ca(OH)_2 + H_2O + SO_2 + 1/2\, O_2 = CaSO_4 * 2\, H_2O \quad (R13)$$
$$CaSO_3 * 1/2\, H_2O + 1/2\, O_2 = CaSO_4 * 1/2\, H_2O \quad (R14)$$
$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O \quad (R15)$$
$$Ca(OH)_2 + 2\, HCl = CaCl_2 + 2\, H_2O \quad (R16)$$
$$Ca(OH)_2 + 2\, HF = CaF_2 + 2\, H_2O \quad (R17)$$

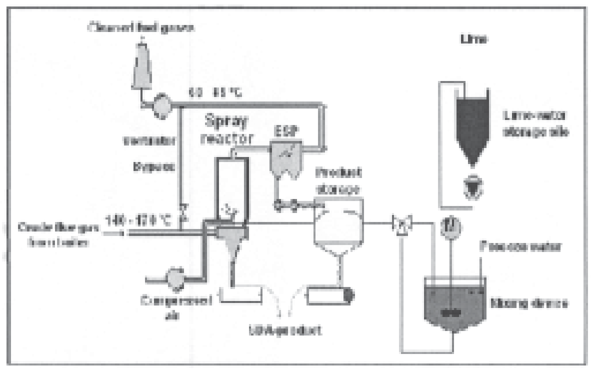

Fig. 9. Dry FGD diagram [14]

The operating principle of SNCR

SNCR installation consists of a storage tank equipped with a truck unloading facility and two submersible pumps to transport the reducing agent from the storage tank to the boiler. For SNCR the most common chemical reducing agents used are ammonia and urea solutions $(NH_2)_2CO$ [16].

Transport of the reducing agent will be through metal pipes using a loop back. Reducing agent has a solidification temperature around 10 ° C, so the tank and pipes must be insulated and heated locally.

Mixing and measuring modules are mounted near the boiler and are equipped with fittings and instruments for measuring and dosing of the reducing agent. Spray lance are placed inside the boiler and are designed to ensure uniform distribution of the reducing agent throughout the cross section of the boiler.

Reducing agent must be sprayed in the boiler furnace on the flue gases at a temperature of 850-1100 ° C. Chemical reactions upon which flows reducing process are [15]:

$Ca(NH_2)_2 + 2NO + 1/2\ O_2 = 2N_2 + CO_2 + 2H_2O$ (R18)

$4NH_3 + 4NO + O_2 = 4N_2 + 6H_2O$ (R19)

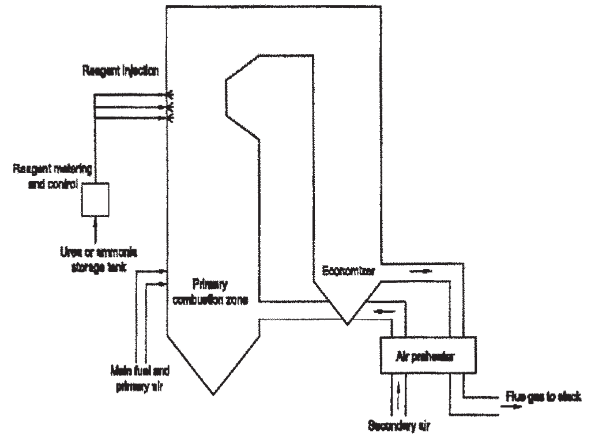

Fig. 10. Boiler with SNCR installation

The operating principle of dense slurry station

Dense slurry technology is the process for the preparation of the mixture slag / ash with water to obtain a biphasic (solid-liquid) homogeneously - slurry, on the one hand, and on the other hand, the process involves the storage of the slurry based on solidifying the biphasic mixture (slurry) in storage dump resulting so-called "stone of ashes."

This technology can be implemented in existing or in a new thermal power plant. The main chemical reactions that describe the phenomenon of cement are:

-generating ions of calcium and sulfate:

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad (R20)$$

$$CaSO_4 + H_2O \rightarrow Ca^{++} + SO_4^{--} \qquad (R21)$$

-ash stone formation:

$$Ca^{++} + OH^- + SO_4^{--} + Al_3O_3 + H_2O \rightarrow 3CaO \cdot 3CaSO_4 \cdot 31 - 32H_2O \qquad (R22)$$

-formation of calcium silicate hydrate:

$$Ca^{++} + OH^- + SiO_2 + H_2O \rightarrow CSH \qquad (R23)$$

Other pollutants control technologies that can be applied on this coal fired boiler in response to new requirements of air quality as well state of art for the pollutant emissions:

-gas reburning in combination with SNCR may achieve a reduction up to 70% [11];

-a SNCR station co-injecting lime slurry with aqueous urea can also control others pollutants SO_2, chlorides and dioxins and furans [11];

- waste water from the power plants without proper treatment can not be discharged into local streams, rivers, and sewers. Waste water can be injected in the furnaces with simultaneous control of NO_x [11];

- co-combustion between biomass and solid fuels results in reduction of SO_2. At a mass share of 30 wt % sawdust in the mixture can achieve a reduction of the emission of SO_2 by 50% [12];

- a direct contact between flue gases and calcium carbonate suspension and between these gases and potassium carbonate solution results in a reduction SO_2 and CO_2 from the flue gas [13].

Results and discussions

As input data were used measurements recorded at the chimney in 2012 before retrofitting the power plant.

This power plant has the role to provide thermal heat to the municipality of Timisoara, in the cold season. To retrieve the necessary heat for domestic hot water comes into operation CET center that works on gas and heavy oil. In table 1 values are the average monthly emissions at the stack.

Table 1
POLLUTANT EMISSION IN 2012

Month	SO2 (mg/m3N)	Nox (mg/m3N)	PM2.5 (mg/m3N)	CO (mg/m3N)	Wet gas volume	Dry gas volume
1	2238.12	368.36	35.61	41.87	256380	180301
2	2262.64	446.86	42.27	40.83	253619	175960
3	2397.57	483.03	47.58	41.5	199197	137159
4	2411.51	458.52	46.45	41.56	228742	155670
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	0	0
10	744.87	145.11	15.05	13.49	82602	58091
11	1375.49	277.39	29.44	22.98	140712	98957
12	1436.5	306.96	19.38	24.43	149591	105201

In table 2 the authors indicate the emission average monthly values after retrofitting in 2014 from the stack.

Table 2
POLLUTANT EMISSION IN 2014

Month	SO2 (mg/m3N)	Nox (mg/m3N)	PM2.5 (mg/m3N)	CO (mg/m3N)	Wet gas volume	Dry gas volume
1	764.35	337.89	36.22	51.31	163415	118270
2	546.62	263.07	6.37	196.76	324423	331851
3	517.89	248.69	16.35	441.99	368049	334713
4	136.52	95.64	2.76	436.77	259216	213511
5	0.00	0.00	0.00	0.00	0	0
6	0.00	0.00	0.00	0.00	0	0
7	0.00	0.00	0.00	0.00	0	0
8	0.00	0.00	0.00	0.00	0	0
9	0.00	0.00	0.00	0.00	0	0
10	100.00	39.51	1.78	71.67	40192	34107
11	447.48	197.34	10.72	269.82	312338	271654
12	683.64	169.33	12.22	238.75	337058	288260

It can be seen that the desulfurization plant had a percentage of SO_2 emission reduction between 67-94%. Following this retrofitting, one has obtained a reduction of the NO_x emissions between 41-80% and a reduction of the PM2.5 around 66%.

To a clearer view on the effect that it has this power plant retrofitting on the human health was made a simulation of the dispersion of emissions from the stack. The program used to simulate the dispersion is ISC3 VIEW that is the most used program for simulation and determination of air quality.

In the following figure authors have presented the annual concentrations of NO_x from SUD CET Timisoara, and their influence on air quality in different areas before retrofitting. Following this simulation one obtained a maximum concentration of NO_x in air, at ground level, that is 10μg/$m^3{}_N$ in Calea Sagului (residential area that is situated in the neighborhood of the CET SUD power plant). In the center of Timisoara, one obtained a concentration of 2 μg/$m^3{}_N$.

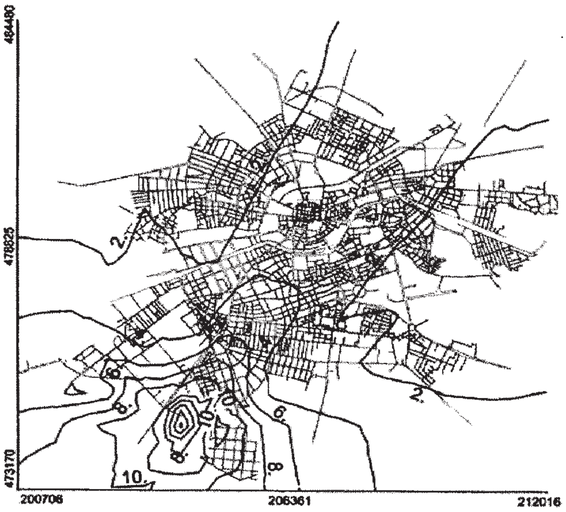

Fig.11. Dispersion of NO_X from CET SUD 2012 [values in μg/$m^3{}_N$]

In figure 12 the authors present the annual air quality concentrations of NO_X from SUD CET Timisoara, and their influence on air quality in different areas after retrofitting. Following this simulation one obtained maximum concentration of NO_X at ground level, around 5.5-6 μg/$m^3{}_N$ around the source. In the center of Timisoara we give a concentration of between 1-1.5μg/$m^3{}_N$ generated by CET SUD. Thus we see a relative improvement of the concentrations of NO_X after retrofitting around the source 4-5 μg/$m^3{}_N$ and downtown 0.5-1 μg/$m^3{}_N$.

Another environmental problem to be solved is the concentrations of SO_2. In the following figure authors have presented the annual concentrations of SO_2 from CET SUD, and their influence on air quality in different before retrofitting. Following this simulation one obtained maximum concentrations of SO_2 of 55 μg/$m^3{}_N$ around the source, at ground level, In the center of Timisoara one obtains a concentration of 25-15 μg/$m^3{}_N$ generated by CET SUD in 2012.

In figure 14 authors have presented the annual air quality concentrations of SO_2 due to the emission from CET SUD Timisoara, and their influence on air quality in

Fig.12. Dispersion of NO_X from CET SUD 2014 [values in μg/$m^3{}_N$]

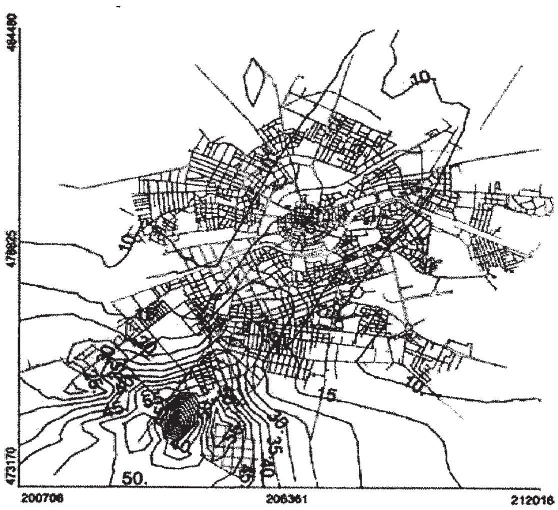

Fig.13. Dispersion of SO_2 from CET SUD 2012 [values in μg/$m^3{}_N$]

Fig.14. Dispersion of SO_2 from CET SUD 2014 [values in μg/$m^3{}_N$]

Fig.15. Dispersion of $PM_{2.5}$ from CET SUD 2012 [values in μg/$m^3{}_N$]

different areas after retrofitting. Following this simulation we obtained maximum concentrations of SO_2 at ground level, between 13.5-14 μg/$m^3{}_N$ around the source. In the center of Timisoara a concentration of between 1.5-3.5 μg/$m^3{}_N$ generated by CET SUD resulted. Thus a relative improvement after upgrading of the concentrations of SO_2 around the source of 40-42 μg/$m^3{}_N$, and in the center 10-11.5 μg/$m^3{}_N$ is stated.

Fig.16. Dispersion of $PM_{2.5}$ from CET Sud Power Plant Timisoara, by 2014, (values in $\mu g/m^3_N$)

In figure 15 authors have presented the annual air quality concentrations of $PM_{2.5}$ at CET Sud, and their influence upon air quality, in different areas, before retrofitting. Following this simulation one obtained maximum concentration of PM2.5 at ground level, at a level of 1 $\mu g/m^3_N$ around the source. In the center of Timisoara a concentration of 0.3-0.5 $\mu g/m^3_N$ generated by CET SUD in 2012 is resulting.

In the following figure we can observe the annual air concentrations of PM2.5 at CET SUD stack and their influence on air quality in different areas after retrofitting. Following this simulation, one obtained maximum concentration of PM2.5 in air, at ground level, of 0.4 $\mu g/m^3_N$, around the source. In the center of Timisoara one obtained a concentration of between 0.08-0.12 $\mu g/m^3_N$ generated by CET SUD. Thus we see a relative improvement after upgrading of the concentrations of $PM_{2.5}$ around the source of 0.6$\mu g/m^3_N$, and in the down town of 0.2 $\mu g/m^3_N$.

Following this retrofitting have not been implemented methods of reducing CO_2 emissions, such a simulation and a comparison of CO_2 concentrations is not eloquenct.

Conclusions

In 2014 Transelectrica, the Romanian Transmission and System Operator reported an hourly average of 7242.75 MW of which 2073.41 MW produced in power plants with solid fuel. Thus around 30% of the electricity produced in Romania is obtained in solid fuel power plants [7].

Many of these power plants provide thermal heat for heating settlements in the area, as in this case, CET SUD Timisoara providing heat during cold season for residents of the city. Keeping these power plants in operation and fulfillment of environmental conditions on pollutant emissions is important thread for the Romanian economy and standard of living of the population in the area.

The good results obtained after upgrading from CET Sud Timisoara show that there are solutions for the existing power plants to fulfill emissions standards imposed by the EU.

One can get significant reductions of air quality concentrations of main pollutants from power plants.

To a clearer view on the effect that it has this power plant retrofitting on the human health was made a simulation of the dispersion of emissions from the stack obtaining the air quality concentrations in the area of Timisoara.

Thus authors accomplished a comparison between concentrations before and after retrofitting with the results presented in this paper. For NO_X concentrations authors presented a 50% decrease around the source and in the down town a decrease between 25-50%.

For SO_2 concentration, the authors conclude a 75% decrease around the source and in the downtown a decrease around 60%.

For PM2.5 after the simulation of the emissions concentrations from the flue gas recorded before and after retrofitting, one achieved a reduction in air quality concentrations of 60% around the source and 70% in the city center that is a very important result. Following this retrofitting besides the improvement of air quality in urban Timisoara, Romania could avoid penalties from the EU.

In the world engineers make efforts to optimize the technologies for controlling pollutants.

ISC3 VIEW use mathematical and numerical techniques to simulate the dispersion of air pollutants as they disperse in the atmosphere. These simulations of pollutant emission are widely used by environmental protection agencies tasked with controlling air pollution, to identify the main pollutants sources and determine strategies to reduce pollution levels. This simulation program is preferred and recommended by U.S. Environmental Protection Agency (EPA) to estimate the concentration of pollutants at ground level receptors around the emission source. In a unstable case estimating rates of dispersion can be alter up to a factor of 2 or 3. The absolute validity of the results can only be found by comparison with physical observation of dispersion.

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