Assessing the environmental pollutant vector of combustion gases emission from coal-fired power plants

Cornelia A. Bulucea, Andreea Jeles, Nikos E. Mastorakis, Carmen A Bulucea, Constantin Brindusa

Abstract Within the present industrial metabolism, electric and thermal energy production is one of the main consumers of fossil fuels. Coal is a natural resource and fossil fuel used in the coal-fired power plants in Romania. Unfortunately, beyond the environmental depletion, the problems caused by the environmental releases in operation of these power plants are also related to human health impact. This paper highlights some of these problems, analyzing the pollutant vector of combustion emissions and the specific physical parameters associated to a coal-fired power plant in Romania. The environmental pollutants belonging to combustion gases vector, as sulfur dioxide SO₂, nitrogen oxides NOₓ, particulate matter PM, and carbon dioxide CO₂, have been analyzed for the Energetic Power Plant of Turceni – Romania. Mathematical models of environmental pollutant vector, estimating the emission factors specific to fossil fuel combustion process have been applied for the thermo-electrical blocks on 330 MW of Turceni power plant. For each combustion gases component of pollutant vector, the results with regard to emission factor and pollutant concentration are presented in this study. Also, the Projection in the Mirror of the combustion gases pollutant vector had allowed an evaluation of mass concentration of the ash in the combustion gases quill. In this case study for the thermo-electric blocks of 330 MW of Turceni power plant, the projection in mirror is developed for distances of 300 meters, and for modelling the ascendant smoke quill according to this projection in mirror, it has been adopted the FDP pattern - probability density function, elaborated by Weil. Accordingly, the nomograms of ash-particulate matter pollutant have been simulated.

Keywords Coal-fired power plant, Combustion gases, Environmental impact, Pollutant vector,

I. CONCERNS RELATED TO COAL-FIRED POWER PLANT OPERATION

Communities all across the world as well as international organizations and agencies are concerned about the environmental and human health impact of burning fossil fuels, and coal in particular [1,2]. Within the present industrial metabolism, electric and thermal energy production is one of the main consumers of fossil fuels [3,4]. Coal is a natural resource and fossil fuel used in the coal-fired power plants in Romania and worldwide. Unfortunately, beyond the environmental depletion, the problems caused by the environmental releases in operation of these power plants are also related to human health impact.

As is widely known, the combustion of coal strongly contributes to acid rain and greenhouse gas, having been connected with global warming [5]. During the electrical energy production, coal—aired power plants emit particulate matter, as well as gases that undergo chemical reactions to form fine particles in atmosphere, such as SO₂, NOₓ and particulate matter [5,6]. These emissions of particulate matter, sulfur dioxide and nitrogen oxides increase the environment concentration of particulate matter less than 2.5 microns in diameter over hundreds to thousands of kilometers downwind of the power plants. In addition to the environmental and human health harm caused by greenhouse gas emissions, coal-fired power plants emit massive amounts of toxic air pollutants that result in significant numbers of deaths and diseases [1]. Being exposed to these pollutant emissions, people are experiencing heart diseases, respiratory illness and lung cancer that could be caused by the coal-fired power plants. Air pollution from coal-fired power plants is also associated with other health outcomes, such as infant death, chronic bronchitis, asthma, adverse reproductive outcomes and other lung diseases [6,7,8]. Consequently, one could notice that coal pollutants from the thermo-electric power plants has: (1) respiratory effects, such as lung affection, asthma attacks, chronic obstructive pulmonary diseases.; (2) cardiovascular effects, since air pollution is known to negatively impact cardiovascular health, and (3) nervous system effects, because the nervous system is also a target of coal pollution’s health impact, since the same mechanism that effects the coronary arteries because of the air pollutants is also applied to the arteries that nourish the brain [1,2,6,7,8].
II. COMPONENTS OF COMBUSTION GASES POLLUTANT VECTOR

Over time it had been concluded that there are real technical difficulties in removing the impurities from the solid fuel prior to combustion, because of the chemical composition of coal [3]. Currently, new technology is being developed [3,9,10,11], aiming either to reduce the emission of power stations by implementation of coal washeries, technologies in "scrubber" and electrostatic precipitators designs which filter the exhaust air, or applying the carbon capture and storage of emissions from coal–fired power stations. Even so, the environmental and human health impact caused by the pollutant emission vector of coal-fired power plants should concern authorities and researchers as well. The most important environmental and human health pollution caused by the coal-fired power plants comes from the emission into the air of gases, that entail sulfur dioxide, nitrogen oxides, particulate matter and carbon dioxide.

A. Sulfur Oxides \( \text{SO}_x \)

Sulfur oxides \( \text{SO}_x \) caused by the coal-fired power plant operation are representing the main source for atmosphere pollution, roughly 60% of total emissions. They are the result of coal combustion. By combustion, sulfur is oxidized in sulfur trioxide \( \text{SO}_3 \) and sulfur dioxide \( \text{SO}_2 \) [12]. The conversion of sulfur dioxide to sulfur trioxide takes place in the flame with oxygen excess, as well as on the path of gas, in the presence of vanadium and iron oxides, which have a catalyst effect at temperatures higher than 800°C. The emissions of sulfur oxides represent roughly 5.9 g/kWh for the thermoelectric stations in operation on basis of coal with 1% sulfur content.

Released into the atmosphere, sulfur dioxide is combining with oxygen under the action of ultraviolet radiation, following the transformation in sulfur trioxide according to:

\[
2\text{SO}_2 + \text{O}_2 + h\nu \rightarrow 2\text{SO}_3
\]

where \( k \) is the constant of Planck and \( \nu \) is the radiation frequency.

Further on, the sulfur trioxide combines with water vapor existing in the air, and forms sulfuric acid \( H_2\text{SO}_4 \); during a fog time the reaction rate is accelerated:

\[
\text{SO}_3 + H_2\text{O} \rightarrow H_2\text{SO}_4
\]  

The presence of sulfur oxides in the atmosphere has direct effects on plants, animals and humans as well, because they are affecting the respiratory system. The effects are also indirect, since the waters and soils composition is modified.

B. Nitrogen Oxides \( \text{NO}_x \)

Nitrogen oxides \( \text{NO}_x \) are known to be radiative and chemically active gases and have significant contribution to the greenhouse effect and main components of acid rain [3,12]. The nitrogen oxides have the origin in two distinct processes:

a) Thermal process which consists in the oxidation of atmospheric nitrogen to nitrogen oxide NO.

b) Oxidation process of the nitrogen present in the coal fuel.

The thermal process takes place at temperatures higher than 1300°C. In excess of oxygen, the atmospheric nitrogen molecules react with the oxygenated radicals that result from the decomposition of molecular oxygen at high temperatures.

\[
N_2 + O \rightarrow NO + N \quad (3)
\]

The radical \( N \) produced by this reaction and by thermal decomposition of molecular nitrogen reacts with the molecular oxygen:

\[
N + O_2 \rightarrow NO + O \quad (4)
\]

If combustion takes place with excess fuel, it produces radical OH which reacts with radical N:

\[
N + OH \rightarrow NO + H \quad (5)
\]

The formation of NO is strongly endothermic in this case, and consequently affected by the temperature; it is produced where the combustion temperature is superior to 1300°C. Hence, in the paths of high thermal load will form more NO than in the paths of low thermal load. By reducing the temperature just below 1300°C, the amount of nitrogen oxide will be significantly decreased.

Formation of nitrogen oxides starting from the nitrogen existing in the fuel is a complex process, still poorly known in detail. In the first stage one could consider the appearance of secondary compounds (hydrocyanic acid HCN, amines NH2, cyanides CN) which are evolving in the presence of oxygen, forming nitrogen monoxide and molecular nitrogen. Activation energy for molecular nitrogen forming is slightly lower than that required for the formation of nitrogen monoxide. This minimum difference explains the little influence of temperature in the two mechanisms. Consequently, the process of nitrogen monoxide forming is actually over just at the rear of the flame front [4,12]. The key parameters of this process are the oxygen concentration and the initial nitrogen content of the fuel.

In coal combustion, the formation mechanism of the nitrogen oxides starting from the fuel nitrogen content, oxygen concentration in the flame and the contact time have a secondary influence. The process is characterized by the nitrogen conversion degree, which is defined as the ratio of nitrogen oxides produced and the maximum amount of nitrogen oxides resulting from a total transformation.

At low temperatures the conversion rate is strongly depending on temperature, while at high temperatures it tends to become independent.

The nitrogen monoxide from air or fuel is oxidized in nitrogen dioxide \( \text{NO}_2 \), as follow:

- at the rear of the flame front:

\[
\text{NO} + H_2\text{O} \rightarrow \text{NO}_2 + H_2 \quad (6)
\]

- in the gas pipes and in the chimney:

\[
2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2 \quad (7)
\]

Hence, nitrogen dioxide is discharged mostly into the atmosphere.

C. Carbon Monoxide \( \text{CO} \) and Carbon Dioxide \( \text{CO}_2 \)

Carbon monoxide \( \text{CO} \) and carbon dioxide \( \text{CO}_2 \) result from the oxidation of carbon that exists in all fuels [3,4,12,13].

Carbon monoxide results from an incomplete oxidation, when the oxygen content is insufficient, and the combustion is running in deficit or low excess of the air. A high excess of the air leads to nitrogen oxide increase, while their decrease is related to the air excess, which favors the formation of carbon monoxide.
D. Particulate Matter PM

Particulate matter PM produced by the thermoelectric and thermal plants are presented as fly ash and ash [3,12,14]. The content of fly ash is a mixture of coal, metal oxides, salts. Composition and characteristics of solid emissions are related to the nature of fuel, as well as to the combustion techniques.

Another source of particulate matter is represented by the substances used for elimination of sulfur oxides, such as CaCO3, CaO, MgCO3, and by the compounds resulting from the treatment, such as CaSO4, Mg:Ca(SO4)2.

Studies [6,7,8] show that exposure to particulate matter can be harmful and have negative health impacts, having been related to an increase of respiratory and cardiac mortality. Particulate matter can irritate small airways in the lungs, which can lead to increased problems with asthma, chronic bronchitis and airway obstruction.

III. CASE STUDY. COMBUSTION GASES POLLUTANT VECTOR OF TURCENI POWER PLANT

Nowadays, the pollution caused from coal-fired power plants comes from the emission of gases (carbon dioxide, nitrogen oxides, sulfur dioxide) and from particulate matter into the air. These react with the atmosphere and create acidic compounds, such as sulfurous acid, nitric acid and sulfuric acid, that fall as rain, hence the term of acid rain [1,6,8].

This case study deals with the thermoelectric blocks of 330 MW of Turceni-Romania power plant. The main technical characteristics of a 330 MW generator (see Fig.1) are depicted in Table I [15].

A. Emission Evaluation with DSDE Methodology

Knowledge of combustion gases emission during the operation of a coal-fired power plant is an essential step in assessing the environmental and human health impact of pollutants.

Table II presents the limit values of combustion gases emission which are admitted by European and Romanian legislation [16].

This paper deals with combustion gases pollutant vector, and the assessment of the pollutant emissions from Turceni power plant is based on DSDE Methodology.

This methodology is elaborated by the Strategy and Economic Development Division within Romanian Electrical Department as calculation method (PE-1001) based on the mathematical models that are depicting the emission factors specific to fuel combustion process. By definition, the emission factor represents the pollutant amount evacuated in atmosphere per heat quantity unit produced by fuel combustion in the boiler [4,15,16].

For distinct pollutants the emission factors are determined experimentally. They are depending on fuel characteristics, constructive type of the combustion installation, as well on fuel calorific power. Emission factors can be corrected in accordance with the fuel composition and the applied combustion technology. Fuel amount and according calorific power are determined by fuel lot.

For coal combustion one could perform a calculation correction of fuel amount, by exclusion of unburned matter content in ash and slag. One could also notice that in case of several fuel types utilization, the total amount of a certain pollutant is determined by summing the emissions corresponding to each of them.

The flow of the pollutant evacuated into the atmosphere (the emission) is determined as:

\[ E_{pol} = B \cdot H_{ic} \cdot e_{pol} \text{[kg/h]} \]  

where: \( E_{pol}\) is the flow of pollutant evacuated into atmosphere; \( B\) is the fuel flow; \( H_{ic}\) is the inferior calorific power of fuel, and \( e_{pol}\) is the emission factor.

Mass concentration of the pollutant evacuated by combustion is determined as:

\[ C_{m,pol} = \frac{E_{pol} \cdot 10^6}{D_{gas}} \text{[mg/m}^3\text{]} \]

where: \( E_{pol}\) is the mass flow of pollutant evacuated into atmosphere, and \( D_{gas}\) is the volume flow of combustion gases.

<table>
<thead>
<tr>
<th>No.</th>
<th>Technical characteristics</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Apparent power</td>
<td>388 MVA</td>
</tr>
<tr>
<td>2</td>
<td>Active power</td>
<td>330 MW</td>
</tr>
<tr>
<td>3</td>
<td>Speed</td>
<td>3000 rpm</td>
</tr>
<tr>
<td>4</td>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>5</td>
<td>Voltage</td>
<td>24 kV</td>
</tr>
<tr>
<td>6</td>
<td>Electric current</td>
<td>9334 A</td>
</tr>
<tr>
<td>7</td>
<td>Phase number</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>Phase connection</td>
<td>Y</td>
</tr>
</tbody>
</table>
A1) Model of Pollutant SO\(_2\). The emission factor for sulfur dioxide is:

\[
\frac{M_{SO_2} \cdot S}{H_c} \cdot (1-r) \text{ [kg/kJ]} \quad (10)
\]

where: \(e_{SO_2} \text{ [kg/kJ]}\) is the emission factor for SO\(_2\); \(M_{SO_2} \text{ [kg/kmol]}\) is the molecular mass of SO\(_2\); \(M_s \text{ [kg/kmol]}\) is the molecular mass of sulfur; \(S\%\) represents the sulfur amount into the fuel; \(iCH \text{ [kJ/kg]}\) is the inferior calorific power of the fuel, and \(r\) is the retention degree of sulfur in slag and ash (see Table III).

A2) Model of Pollutant NO\(_x\). Calculation of NO\(_x\) emission is based on the emission factors that are indicated on Table IV, applying then an oxygen correction for a 100% load of the boiler.

TABLE IV

<table>
<thead>
<tr>
<th>Fuel</th>
<th>50 - 100</th>
<th>100 - 300</th>
<th>&gt;300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td>2*10^{-1}</td>
<td>2*10^{-1}</td>
<td>2*10^{-1}</td>
</tr>
<tr>
<td>Coal</td>
<td>3,8*10^{-1}</td>
<td>4,2*10^{-1}</td>
<td>4,5*10^{-1}</td>
</tr>
<tr>
<td>Oil</td>
<td>1,9*10^{-1}</td>
<td>2,1*10^{-1}</td>
<td>2,8*10^{-1}</td>
</tr>
<tr>
<td>Natural gas</td>
<td>1,3*10^{-1}</td>
<td>1,5*10^{-1}</td>
<td>1,7*10^{-1}</td>
</tr>
</tbody>
</table>

For the emission calculation at partial loads (>50%) the following correction it is applied:

\[
e_{NO_x}^e = e_{NO_x}^{100} \cdot \left[ a + (1-a) \frac{L - 50}{50} \right] \text{ [kg/kJ]} \quad (11)
\]

where: \(e_{NO_x}^e \text{ [kg/kJ]}\) is the emission factor at load \(x\); \(e_{NO_x}^{100} \text{ [kg/kJ]}\) is the emission factor at load 100%; \(L\%\) is the boiler load, and \(a\) is the fuel type coefficient, according to Table V.

A3) Model of Pollutant particulate matter (ash and dust). Calculation of emission factor specific to particulate matter pollutant is determined as follows:

\[
e_{pub} = \frac{(1-x/100)(1-y/100) \cdot A/100}{H_c} \text{ [kg/kJ]} \quad (12)
\]

where: \(e_{pub} \text{ [kg/kJ]}\) is the emission factor for ash; \(A\%\) is the ash content in the coal; \(x\%\) is the retention degree of ash in the focus; \(y\%\) is the yield of the installation for dust retention; \(H_c \text{ [kJ/kg]}\) is the inferior calorific power of fuel.

A4) Model of Pollutant CO\(_2\). Emission factors for CO\(_2\), according to European Union regulation, are depicted in Table VII.

TABLE VII

<table>
<thead>
<tr>
<th>Fuel</th>
<th>(e_{CO_2}^{100})</th>
<th>g/GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (lignite)</td>
<td>98*10^{-3}</td>
<td>98000</td>
</tr>
<tr>
<td>Oil</td>
<td>72*10^{-3}</td>
<td>72000</td>
</tr>
<tr>
<td>Natural gas</td>
<td>50*10^{-3}</td>
<td>50000</td>
</tr>
</tbody>
</table>

Calculation of emission factor specific to pollutant CO\(_2\) is determined as:

\[
e_{CO_2} = \frac{M_{CO_2} \cdot C}{H_c} \cdot \frac{100}{100} \text{ [kg/kJ]} \quad (13)
\]

where: \(e_{CO_2} \text{ [kg/kJ]}\) is the emission factor for CO\(_2\); \(M_{CO_2} \text{ [kg/kmol]}\) is the molecular mass of carbon; \(C\%\) is the carbon content in the fuel; \(H_c \text{ [kJ/kg]}\) is the inferior calorific power of the fuel.

B. Projection in Mirror of Combustion Gases Pollutant Vector

The combustion gases pollutant vector is depicted [17,18,19] by origin, direction, sense and magnitude:

- pollutant vector origin is represented by the gases evacuation chimney of the power plant;
- pollutant vector direction has a temporary character and it is defined mainly by the climate factors, wind speed having been the most important;
- pollutant vector sense is defined by the evacuation chimney for the combustion gases;
- pollutant vector magnitude is determined by the content of pollutants, that is variable, decreasing as distance increased from the chimney.
The Projection in the Mirror of the pollutant vector allows the evaluation of the mass concentration of ash in the combustion gases quill, on distances of several hundred meters [19,20,21]. This projection is based on the symmetry between the combustion gases chimney and the combustion gases quill related to a higher symmetry axis (see Fig.2).

This way the combustion gases quill can be equated to a body as symmetrical truncated cone (see Fig.3). One could notice that the concentrations of ash and combustion gases pollutants are inverse proportionally with the truncated cone height Table VIII).

\[
\text{TABLE VIII}
\]

<table>
<thead>
<tr>
<th>No.</th>
<th>Iso-mass curves</th>
<th>Iso = Iso-mass indicative</th>
<th>(D_{iiso} [m]) = distance on iso-mass curve</th>
<th>(K [mg/m^3/m] = \text{linearization longitudinal coefficient})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Iso600</td>
<td>600</td>
<td>50</td>
<td>100 / 50</td>
</tr>
<tr>
<td>2</td>
<td>Iso500</td>
<td>500</td>
<td>50</td>
<td>100 / 50</td>
</tr>
<tr>
<td>3</td>
<td>Iso400</td>
<td>400</td>
<td>50</td>
<td>100 / 50</td>
</tr>
<tr>
<td>4</td>
<td>Iso300</td>
<td>300</td>
<td>50</td>
<td>100 / 50</td>
</tr>
<tr>
<td>5</td>
<td>Iso200</td>
<td>200</td>
<td>50</td>
<td>100 / 50</td>
</tr>
<tr>
<td>6</td>
<td>Iso100</td>
<td>100</td>
<td>50</td>
<td>100 / 50</td>
</tr>
</tbody>
</table>

C. DSDE Methodology Applied to Thermoelectric Blocks of 330 MW of Turceni Power Plant

This case study is performed in Turceni power plant, for 33.33% of installed power, that is corresponding to 2 thermoelectric blocks (n=2) of 330 MW in operation for an hour on basis of lignite-fired [15,16]. Mathematical models of the methodology DSDE has been used for depicting the emission factors specific to fuel combustion in the thermoelectric blocks of Turceni power plant. The following operation conditions are assumed in this case study:

a) operation of Turceni power plant at 33.33% capacity of installed power, with 2 thermoelectric blocks (n=2) of 330 MW;
b) 1 chimney for combustion gas, that is evacuating the pollutants from the two thermoelectric blocks, mentioned as above;
c) fuel type is lignite with the inferior calorific power \(H_{iL} = 6280 \text{kJ/kg}\), sulfur content \(S = 0.8\%\), carbon content \(C = 20\%\), ash content \(A = 25.5\%\), total wet \(W = 45\%\);
d) flow of consumed coal per a thermoelectric block of 330MW is determined on basis of the medium flow of coal pulverized by the 5 coal mills \(5*92.6 \text{t/h}\), and accordingly the lignite flow took into consideration is \(B_L = 5*92.6 \text{t/h} = 463 \text{t/h} = 463*10^3 \text{kg/h}\);
e) oil as fuel support has the inferior calorific power \(H_{io} = 39770 \text{kJ/kg}\), sulfur content \(S = 3\%\), carbon content \(C = 76\%\);
f) the flow of consumed oil per a thermoelectric block of 330 MW is \(B_o = 10*10^3 \text{kg/h}\);

The combustion gases pollutant vector has four main components: sulfur dioxide \(SO_2\), carbon dioxide \(CO_2\), particulate matter PM, nitrogen oxides NOx.

C1) Component \(SO_2\) of pollutant vector

Taking into consideration the DSDE methodology there were resulting: the emission factor for \(SO_2\) by lignite combustion \(e_{iSO_2} \text{[kg/kJ]}\), the flow of pollutant \(SO_2\) evacuated by lignite combustion \(E_{iSO_2} \text{[kg/h]}\), the emission factor for \(SO_2\) by oil combustion \(e_{pSO_2} \text{[kg/kJ]}\), the flow of pollutant \(SO_2\) evacuated by oil combustion \(E_{pSO_2} \text{[kg/h]}\), the total flow of pollutant \(SO_2\) evacuated by combustion \(E_{SO_2} \text{[kg/h]}\), and the mass concentration of pollutant \(SO_2\) evacuated by combustion \(C_{mSO_2} \text{[mg/m}^3\text{]}\). In Table IX there are depicted the data resulting in this case study for the component \(SO_2\) of the gases pollutant vector.

\[
\text{TABLE IX}
\]

<table>
<thead>
<tr>
<th>Parameter (SO_2)</th>
<th>Symbol</th>
<th>(M_u)</th>
<th>Fuel type</th>
<th>Reference values</th>
<th>Case I (n=2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite: fuel flow</td>
<td>(B_L)</td>
<td>kg/h</td>
<td>lignite</td>
<td>463 * 10^3^n</td>
<td>926 * 10^3^n</td>
</tr>
<tr>
<td>Oil: fuel flow</td>
<td>(B_o)</td>
<td>kg/h</td>
<td>oil</td>
<td>10 * 10^3^n</td>
<td>20 * 10^3^n</td>
</tr>
<tr>
<td>Lignite: (SO_2) emission factor</td>
<td>(e_{iSO_2})</td>
<td>kg/kJ</td>
<td>lignite</td>
<td>2.04 * 10^-6</td>
<td>2.04 * 10^-6</td>
</tr>
<tr>
<td>Lignite: (SO_2) pollutant flow</td>
<td>(E_{iSO_2})</td>
<td>kg/h</td>
<td>lignite</td>
<td>5930n</td>
<td>11860</td>
</tr>
<tr>
<td>Oil: (SO_2) emission factor</td>
<td>(e_{pSO_2})</td>
<td>kg/kJ</td>
<td>oil</td>
<td>1.51 * 10^-8</td>
<td>1.51 * 10^-8</td>
</tr>
<tr>
<td>Oil: (SO_2) pollutant flow</td>
<td>(E_{pSO_2})</td>
<td>kg/h</td>
<td>oil</td>
<td>600n</td>
<td>1200</td>
</tr>
<tr>
<td>Total flow of (SO_2) pollutant</td>
<td>(E_{SO_2})</td>
<td>kg/h</td>
<td>all fuels</td>
<td>6530n</td>
<td>13060</td>
</tr>
<tr>
<td>Concentration of (SO_2) pollutant</td>
<td>(C_{mSO_2})</td>
<td>mg/m^3</td>
<td>all fuels</td>
<td>3840</td>
<td>3840</td>
</tr>
</tbody>
</table>
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C2) Component CO₂ of pollutant vector
Taking into consideration the DSDE methodology there are resulting: the emission factor for CO₂ by lignite combustion $e_{LCO_{2}}$ [kg/kJ], the flow of pollutant CO₂ evacuated by lignite combustion $E_{LCO_{2}}$ [kg/h], the emission factor for CO₂ by oil combustion $e_{PCO_{2}}$ [kg/kJ], the flow of pollutant CO₂ evacuated by oil combustion $E_{PCO_{2}}$ [kg/h], the total flow of pollutant CO₂ evacuated by combustion $E_{CO_{2}}$ [kg/h], and the mass concentration of pollutant CO₂ evacuated by combustion $C_{mCO_{2}}$ [mg/m³]. In Table X there are depicted the data resulting in this case study for the component CO₂ of the gases pollutant vector.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>MU</th>
<th>Fuel type</th>
<th>Reference values</th>
<th>Case I (n=2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite: fuel flow</td>
<td>$B_L$</td>
<td>kg/h</td>
<td>lignite</td>
<td>463 $\cdot 10^{3}$</td>
<td>926 $\cdot 10^{3}$</td>
</tr>
<tr>
<td>Oil: fuel flow</td>
<td>$B_P$</td>
<td>kg/h</td>
<td>oil</td>
<td>10 $\cdot 10^{3}$</td>
<td>20 $\cdot 10^{3}$</td>
</tr>
<tr>
<td>Lignite: CO₂ emission factor</td>
<td>$e_{LCO_{2}}$</td>
<td>kg/kJ</td>
<td>lignite</td>
<td>116,8*10^{-6}</td>
<td>116,8*10^{-6}</td>
</tr>
<tr>
<td>Lignite: CO₂ pollution flow</td>
<td>$E_{LCO_{2}}$</td>
<td>kg/h</td>
<td>lignite</td>
<td>33960n</td>
<td>67920</td>
</tr>
<tr>
<td>Oil: CO₂ emission factor</td>
<td>$e_{PCO_{2}}$</td>
<td>kg/kJ</td>
<td>oil</td>
<td>70,1*10^{-6}</td>
<td>70,1*10^{-6}</td>
</tr>
<tr>
<td>Oil: CO₂ pollution flow</td>
<td>$E_{PCO_{2}}$</td>
<td>kg/h</td>
<td>oil</td>
<td>27880n</td>
<td>55760</td>
</tr>
<tr>
<td>Total flow of CO₂ pollutant</td>
<td>$E_{CO_{2}}$</td>
<td>kg/h</td>
<td>all fuels</td>
<td>61840n</td>
<td>123680</td>
</tr>
<tr>
<td>Concentration of CO₂ pollutant</td>
<td>$C_{mCO_{2}}$</td>
<td>mg/m³</td>
<td>all fuels</td>
<td>36380</td>
<td>36380</td>
</tr>
</tbody>
</table>

C3) Component particulate matter PM of pollutant vector
According to the DSDE methodology there are resulting: the emission factor for PM by lignite combustion $e_{PM_{L}}$ [kg/kJ], the flow of pollutant PM evacuated by lignite combustion $E_{PM_{L}}$ [kg/h], and the mass concentration of pollutant PM evacuated by combustion $C_{PM_{L}}$ [mg/m³]. One could notice that ash emission is calculated only for lignite, since it is admitted that oil emission factor is null this time. In Table XI there are depicted the data resulting in this case study for the component PM of the gases pollutant vector.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>MU</th>
<th>Fuel type</th>
<th>Reference values</th>
<th>Case I (n=2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite: fuel flow</td>
<td>$B_L$</td>
<td>kg/h</td>
<td>lignite</td>
<td>463 $\cdot 10^{3}$</td>
<td>926 $\cdot 10^{3}$</td>
</tr>
<tr>
<td>Oil: fuel flow</td>
<td>$B_P$</td>
<td>kg/h</td>
<td>oil</td>
<td>10 $\cdot 10^{3}$</td>
<td>20 $\cdot 10^{3}$</td>
</tr>
<tr>
<td>Lignite: Particulate matter PM emission factor</td>
<td>$e_{PM_{L}}$</td>
<td>kg/kJ</td>
<td>lignite</td>
<td>0,345*10^{-6}</td>
<td>0,345*10^{-6}</td>
</tr>
</tbody>
</table>

C4) Component NOx of pollutant vector
According to the DSDE methodology there are resulting: the emission factor for NOx by lignite combustion $e_{LNO_{x}}$ [kg/kJ], the flow of pollutant NOx evacuated by lignite combustion $E_{LNO_{x}}$ [kg/h], the emission factor for NOx by oil combustion $e_{NOx_{O}}$ [kg/kJ], the flow of pollutant NOx evacuated by oil combustion $E_{NOx_{O}}$ [kg/h], the total flow of pollutant NOx evacuated by combustion $E_{NOx}$ [kg/h], and the mass concentration of pollutant NOx evacuated by combustion $C_{mNOx}$ [mg/m³]. In Table XII there are depicted the data resulting in this case study for the component NOx of the gases pollutant vector.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>MU</th>
<th>Fuel type</th>
<th>Reference values</th>
<th>Case I (n=2)</th>
</tr>
</thead>
</table>

D. Numerical Validation on Basis of FDP Pattern Applied to Thermoelectric Blocks of 330 MW of Turceni Power Plant

<table>
<thead>
<tr>
<th>No.</th>
<th>Iso-mass curves</th>
<th>Iso = Iso-mass indicative</th>
<th>$C_{m}$[mg/m³] = maximum concentration</th>
<th>k[m²] = correction factor</th>
<th>$z-z_{c}$ [m] = distance on iso-mass curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Iso₃₀₀</td>
<td>590</td>
<td>590</td>
<td>0,000002</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>Iso₃₀₀</td>
<td>400</td>
<td>590</td>
<td>0,000002</td>
<td>135</td>
</tr>
<tr>
<td>3</td>
<td>Iso₃₀₀</td>
<td>300</td>
<td>590</td>
<td>0,000002</td>
<td>185</td>
</tr>
<tr>
<td>4</td>
<td>Iso₃₀₀</td>
<td>200</td>
<td>590</td>
<td>0,000002</td>
<td>235</td>
</tr>
<tr>
<td>5</td>
<td>Iso₃₀₀</td>
<td>100</td>
<td>590</td>
<td>0,000002</td>
<td>300</td>
</tr>
</tbody>
</table>
In this case study, for the thermoelectric blocks of 330 MW of Turceni power plant, the projection in mirror is developed for distances of 300 meters (see Fig. 4 and Table XIII).

Distribution of iso-mass curves in the case of projection in the mirror for isomorphic curves of order 100 mg/m³N in the smoke quill is depicted in Fig. 4.

For the determination by calculation of the mass concentration evolution according to the projection in the mirror of the smoke quill have been developed patterns of diffusion prognosis [15,19] for an appropriate comparison with experimental data and laboratory tests.

In this paper, for modelling the ascendant smoke quill according to the projection in the mirror on a 300 meters distance, it has been adopted the FDP pattern - probability density function, elaborated by Weil [17,19,21]. This model allows entailing the input parameters of the phenomena that govern the pollutant dispersion into the atmosphere.

Accordingly, in Fig. 5 it is depicted the overall nomogram of mass concentration ash-particulate matter (Turceni power plant), the physical parameter being the mass concentration, and in Fig.6, Fig.7 and Fig.8 there are presented the nomograms of ash-particulate matter pollutant for different

![Fig.4 Iso-mass curves: Iso600, Iso500, Iso400, Iso300, Iso200, Iso100](image)

![Fig.5 Overall nomogram of mass concentration ash-particulate matter (Turceni power plant)](image)

![Function = 590*Exp(-0,000019*x*x)](image)

![Fig.6 Mass concentration nomogram for k = 1,9*10⁻⁵ m², and distinct values on Oy axis](image)

![Function = 590*Exp(-0,00002*x*x)](image)

![Fig.7 Mass concentration nomogram for k = 2*10⁻⁵ m² and distinct values on Oy axis](image)

![Function = 590*Exp(-0,000021*x*x)](image)

![Fig.8 Mass concentration nomogram for k = 2,1*10⁻⁵ m² and distinct values on Oy axis](image)
values of correction factor k, with the mass concentration as physical parameter.

IV. CONCLUSION

Knowledge of emissions during the operation of a coal-fired power-plant is an essential step in assessing the environmental and human health impact of pollutants. Procedures should impose worldwide the estimation of yearly emissions of primary particulate matter, sulfur oxides and nitrogen oxides on the total megawatt-hours generated by each power plant. Further on, since the emissions from coal-fired power plants are dispersed over a large area, the population living around every power plant should be included in specific databases and a mapping program, aiming that it could be medically useful.

Since the electricity generation in power plants based on coal-fired is responsible for a large amount of the pollutant emission, within the Sustainable Development framework it is compulsory on each existing coal-fired power plant to be installed and activated both modern pollution control technology and depollution equipment, assuming that these end-of-pipe treatments would reduce the environmental and human health impacts and will slow the process of degradation of life on Earth. Further on, investing in cleaner production to prevent pollution and reduce coal-resource consumption should be a responsible approach, more effective than continuing to apply the end-of-pipe solutions in the coal-fired power plants.

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REFERENCES


