METHOD FOR EMISSIONS CALCULATION FOR COGENERATION POWER PLANT USING EMISSION FACTORS

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In this article a mathematic model for emission factors and emissions amount calculation for cogeneration power plants currently used for supply energy and heat for cities is developed. The article also analyses the effect of different percentages of fuel oil use for the main pollutants issued from burning process, for combined heat and power generation in periods when natural gas is not available at normal parameters (usually in cold periods).

Keywords: cogeneration, emission factor, environment, climate changes, mathematic model

1. Introduction

Cogeneration is defined as the simultaneous generation of heat and electrical energy in the same installation with a common source of fuel [1]. The volatility of fuel costs and electricity prices in deregulated markets, possibility of breakdowns in fuel supply-coupled with the need to secure reliable heat and power supplies for industry and district heating, along with new environmentally based financial incentives-are driving the need for usually use of two fuels for production process in cogeneration power plants.

Power generation in thermal power plants that use fossil fuels (including here and cogeneration power plants) represent also a significant source of pollutants. In this paper is analyzed the case of emissions for cogeneration power plants with steam turbines. The relevant pollutants considered are sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon dioxide (CO_2) and also methane (CH_4) and nitrous oxide (N_2O), for $CO_{2\ equivalent}$ determination. The paper presents two methodes to calculate the pollutant emissions using emission factors:

- a method based on energy content of fuel or conversion method (using the useful energy developed by the combustion of fuel);

- a method based on energy generation efficiency (using efficiency of process).

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2. Definition of emission factors

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant [2]. This is a general definition for emission factors.

These factors are usually expressed as the weight of pollutant divided by a unit of weight, volume, distance, or duration of the activity emitting the pollutant.

Such factors facilitate the estimation of emissions from various sources of air pollution, including power generation plants, thermal power plants, or cogeneration power plants that use fossil fuels. In this case, emission factors for different pollutants can be expressed in units of mass per units of energy resulting from combustion, or in units of mass per units of energy produced. One of the most important uses of emission factors is for reporting of national greenhouse gas inventories under the United Nations Framework Convention on Climate Change (UNFCCC) [3].

This paper focuses on a specific problem: the emissions from the combined generation of electricity and heat based on fossil fuels, using emission factors. Emission factors and emission inventories have been for a long time fundamental tools for air quality management. Emission estimates are important for developing emission control strategies, determining applicability of permitting and control programs, ascertaining the effects of sources and appropriate mitigation strategies, and a number of other related applications by an array of users. The definition and the calculation of the effect scores for the cogeneration systems conduct to the quantification of their ecological impact, which is an important tool both for the implementation of a new cogeneration solution and for an audit realization for the already existent systems. At the same time, depending on the measure unit used to evaluate them, can be a means of comparison of environmental performance between different generation technologies (in this case, a way to highlight the benefits of cogeneration compared to separate generation of energy and heat in terms of the amount of emissions per unit of useful energy produced) [4].

3. Calculation of emissions amount using the useful energy developed by the combustion of fuel using emission factors

This calculation method takes into account the fuel characteristics and its combustion technology. The emission factors are expressed in *g/GJ* and (*very important*) is used to calculate the total emission from a source as an input for the emission inventory [2], both in the case of separate generation of electricity and heat, as well as in the case of generation in cogeneration mode of these two forms of energy. General flow sheet of mathematical model to determine the amount of emissions from a power plant using emission factors calculated based on energy developed by the combustion shown in Fig. 1:

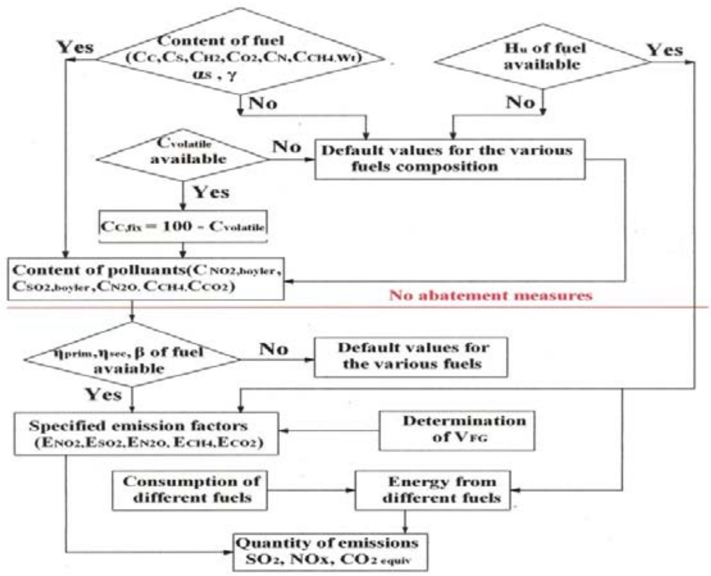

Fig. 1. General flow sheet of mathematical model for emissions determination using emission factors.

Below the calculation of each of the pollutants analyzed is presented in detail, based on energy developed by the combustion.

3.1. Calculation of SO_2 emissions

The emissions of sulphur oxides (SOx) are directly related to the sulphur content of the fuel, which for fuel oil normally varies from 0,3 up to 3,0 wt.-%; usually, the sulphur content of gas is negligible. For the determination of specified SO_2 emission factors the following general equation should be used [5]:

$$EF_{SO_2} = 2C_S(1-\alpha_S)\frac{1}{H_u}10^6(1-\eta_{\sec}\beta) \qquad (1)$$

The value of SO_2 content in flue gas (C_{SO2}) is:

$$C_{SO_2} = EF_{SO_2}\frac{1}{V_{fg}}E_{fuel}\ [\frac{g}{m^3}] \qquad (2)$$

$$E_{fuel} = (FC\,H_u)10^{-3} \qquad (3)$$

Specific air volume (V_a^0) and specific flue gas volume (V_{fg}) can be calculated with formulas [6]:

$$V_a^0 = 1{,}097\frac{H_u}{4186{,}8} + 0{,}0066 w_t^i - 0{,}044 \text{ [Nm}^3\text{/kg fuel oil]} \tag{4}$$

$$V_{fg} = V_a^0 + 0{,}17\frac{H_u}{4{,}186{,}8} + 0{,}001244 w_t^i - 0{,}98 \text{ [Nm}^3\text{/kg fuel oil], for fuel oil} \tag{5}$$

$$V_a^0 = 1{,}06\frac{H_u^{anh}}{4186{,}8} + 0{,}02 \text{ [Nm}^3\text{/Nm}^3\text{ dry natural gas]} \tag{6}$$

$$V_{fg} = V_a^0 + 0{,}38 + 0{,}075\frac{H_u^{anh}}{4186{,}8} \text{ [Nm}^3\text{/Nm}^3\text{ dry natural gas], for gas} \tag{7}$$

$$H_u^{anh} = \frac{H_u}{k} \text{ [MJ/kg]} \tag{8}$$

$$k = \frac{100}{100 + 0{,}1244d} = \frac{100}{100 + (0{,}1244 \times 15)} = 0{,}9817 \tag{9}$$

3.2. Calculation of NOx emissions

The most important oxides of nitrogen formed with respect to pollution are nitric oxide (NO) and nitrogen dioxide (NO_2), jointly referred to as NOx. The main compound is NO, which contributes over 90% to the total NOx. For nitric oxide (NO, together with NO_2 normally expressed as nitrogen oxides NOx) three different formation mechanisms have to be distinguished:

-formation of "fuel-NO" from the conversion of chemically bound nitrogen in the fuel (NOfuel),

-formation of "thermal-NO" from the fixation of atmospheric nitrogen coming from the combustion air (NOthermal),

-formation of "prompt-NO".

In the temperature range considered (up to 1700°C) the formation of "prompt-NO" can be neglected. Depending on combustion temperatures, the portion of thermal-NOx formed is lower than 20%. During the combustion of solid and liquid fuels, fuel-NO and thermal-NO are formed. Natural gas contains no organically bound nitrogen. The content of molecular nitrogen in natural gas has no influence on the formation of fuel-NO; only thermal-NO is formed.

The determination of NOx emission factors takes into account formation of fuel-NO and thermal-NO; the following empirical equations should be used [5]:

The maximum attainable amount of fuel nitrogen oxide ($C_{NO\ fuel\ max}$) is obtained by the following formula:

$$C_{NO\ fuel\max} = C_{N\ fuel}\frac{30}{14}\frac{1}{V_{fg}} \text{ [kg/m}^3\text{]} \tag{10}$$

The fuel-nitrogen content ($C_{N\ fuel}$) is not completely converted into fuel NO; the converted part of fuel-nitrogen to fuel-NO, $C_{NOfuel\ conv}$ can be determined by the following empirical formula related to zero percent of oxygen in dry flue gas and known fuel composition [2]:

$$C_{NO\ fuel\ conv} = 285 + 1{,}280\frac{C_{N\ fuel}}{0{,}015} + 180\frac{C_{volatiles}}{0{,}4}\frac{C_{NO\ fuel\ \max}}{3{,}200} - 840\frac{C_{C\ fix}}{0{,}6}\frac{C_{NO\ fuel\ \max}}{3{,}200} \quad [\text{mg/kg}] \quad (11)$$

$$C_{C\ fix} = 1 - C_{volatiles} \quad (12)$$

The total content of nitrogen oxide formed in the boiler ($C_{NO\ total\ boiler}$) is:

$$C_{NO\ total\ boyler} = C_{NO\ fuel\ conv} + C_{NO\ thermal} = C_{NO\ fuel\ conv}(1+\gamma)\ [\text{kg/kg}] \quad (13)$$

The total boiler emissions of nitrogen dioxide ($C_{NO_2\ boiler}$) can be calculated as follows:

$$C_{NO_2\ boyler} = C_{NO\ total\ boyler}\frac{46}{30}\ [\text{kg/kg}] \quad (14)$$

The total boiler content of nitrogen dioxide given by $C_{NO2\ boiler}$ is reduced by taking into account primary measures with the reduction efficiency (η_{prim}). The result is the content of primary nitrogen dioxide ($C_{NO2\ prim}$):

$$C_{NO_2\ prim} = C_{NO_2\ boyler}(1-\eta_{prim}) \quad [\text{kg/kg}] \quad (15)$$

The emission of primary nitrogen dioxide $C_{NO2\ prim}$ is corrected by the reduction efficiency η_{sec} and the availability β of the secondary measure installed, according to:

$$C_{NO_2\ \sec} = C_{NO_2\ prim}(1-\eta_{\sec}\beta) \quad [\text{kg/kg}] \quad (16)$$

The obtained value of $C_{NO_2\ \sec}$ is converted into C_{NO2} and into the emission factor:

$$C_{NO_2} = C_{NO_2\ \sec}\frac{1}{V_D}10^6\ [\text{kg/kg}] \quad (17)$$

$$EF_{NO_2} = C_{NO_2}\frac{1}{H_u}10^6\ [\text{g/GJ}] \quad (18)$$

The value of NOx content in flue gas (C_{NOx}) is:

$$C_{NOx} = EF_{NO_2}\frac{1}{V_{fg}}E_{fuel}\ [\frac{g}{m^3}] \quad (19)$$

$$E_{fuel} = (FC\,H_u)\times 10^{-3} \quad (20)$$

According to [7], the value of C_{NOx} is calculated for full load of boyler (100%). For partial loads, value of C_{NOx} must be corrected with formula:

$$C_{NOx,x} = C_{NOx,100}[c + (1-c)\frac{L-50}{50}] \quad [\frac{g}{m^3}] \quad (21)$$

NOx emissions are strong influenced by content of oxygen in the flue gas.

If this content is different of standard value O_2^{st} (3% for fuel oil and natural gas, and 6% for coal), the value of C_{NOx} is corrected with formula:

$$C_{NOx}^{cor} = C_{NOx}\frac{21 - O_2^{st}}{21 - O_2^{mas}} \qquad [\frac{g}{m^3}] \tag{22}$$

3.3. Calculation of $CO_{2\ equivalent}$ emissions

Carbon dioxide (CO_2) is a main product from the combustion of all fossil fuels. The CO_2 emission is directly related to the carbon content of fuels. The content of carbon varies for gas, oil and heavy fuel oil about 85 wt.-% [2]. For the determination of specified CO_2 emission factors, the following general equation can be used [5]:

$$EF_{CO_2} = \frac{44}{12} C_{C\ fuel}\, \varepsilon_C \frac{1}{H_u} 10^6 \ [\frac{g}{GJ}] \tag{23}$$

The value of CO_2 content in flue gas (C_{CO2}) is:

$$C_{CO_2} = EF_{CO_2}\frac{1}{V_{fg}} E_{fuel} \ [\frac{g}{m^3}] \tag{24}$$

Electricity is a significant source of carbon dioxide. Alongside carbon dioxide, methane (CH_4) and nitrous oxide (N_2O) are the most prevalent greenhouse gases from fossil fuels combustion for energy and heat production.

For the determination of specified CH_4 emission factors, the following general equation can be used [5]:

$$EF_{CH_4} = C_{CH_4\ fuel}\, \varepsilon_{CH_4} \frac{1}{H_u} 10^6 \ [\frac{g}{GJ}] \tag{25}$$

Lower combustion temperatures, particularly below 1000°C, cause higher N_2O emissions. For the determination of specified N_2O emission factors, the following general equation can be used [5]:

$$EF_{N_2O} = \frac{44}{14} C_{N\ fuel}\, \varepsilon_N \frac{1}{H_u} 10^6 \ [\frac{g}{GJ}] \tag{26}$$

Each greenhouse gas has active radiative or heat-trapping properties. To compare greenhouse gases, they are indexed according to their Global Warming Potential (GWP). This is the ability of a greenhouse gas to trap heat in the atmosphere relative to an equal amount of carbon dioxide. Carbon dioxide assumes the value 1(one). Methane (CH_4) and nitrous oxide (N_2O) are also greenhouse gases and have a global warming potential: value 21 for CH_4 and value 310 for N_2O respectively; they are long-lived in the atmosphere in a similar way to CO_2 [8]. The effects are estimated by converting these gases into CO_2 equivalent. Carbon dioxide equivalency is a quantity that describes, for a mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential, when is measured over a specified timescale (generally, 100 years); is obtained by multiplying the mass and the GWP of the gas:

$$EF_{CO_2\,equivalent} = GWP_{CO_2} EF_{CO_2} + GWP_{CH_4} EF_{CH_4} + GWP_{N_2O} EF_{N_2O} \quad (27)$$

The value of $CO_{2\,equivalent}$ content in flue gas ($C_{CO2\,equiv}$) is:

$$C_{CO_2\,equiv} = EF_{CO_2\,equiv} \frac{1}{V_{fg}} E_{fuel} \; [\frac{g}{m^3}] \quad (28)$$

3.4. Results of numerical calculations

Numerical calculations refer to the production of emissions from the combustion of natural gas mixed with different percentages of fuel oil (with 0,51% sulphur content): 10%, 30%, 50%, 70% and 90% respectively, and from the combustion of natural gas 100%.

Baseline data: $H_{u,fuel\,oil}$ = 9650 kcal/kg = 40,3756 MJ/kg

$C_{S,fuel\,oil}$ = 0,51%

$w^{i}_{t\,fuel\,oil}$ = 0,2%

H^{gas}_{u} = 8200 kcal/Nm^3 = 34,3088 MJ/Nm^3 natural gas

$H^{anh}_{u} = \frac{H^{gas}_{u}}{0,9817}$ = 34,948 MJ/Nm^3 dry natural gas

Calculated data: V^{0}_{a} = 10,536 Nm^3/kg fuel oil

V_{fg} = 11,19 Nm^3/kg fuel oil

V^{0}_{a} = 8,868 Nm^3/ Nm^3 dry natural gas

V_{fg} = 9,874 Nm^3/ Nm^3 dry natural gas

The values of specified emission factors, calculated using above-mentioned methodology, for a boyler with thermal capacity elder 300 MWt in conventional cogeneration power plant with steam turbine, are presented in *Table 1*. The values of emissions are calculated for full load of boiler and without influence of abatement measures for NOx reduction.

Table 1

Values for emission factors

Fuel	Emission factor (EF) [g/GJ]					
	SO_2	NOx	CO_2	N_2O	CH_4	$CO_{2,equiv}$
Natural gas	0 (*)	150	55500	2,4	2,5	56296,5
Fuel oil	252,62(**)	190	76600	14	0,7	80954,7

(*) – for 0% sulphur content in natural gas;

(**) – for 0,51% sulphur content in fuel oil.

The lower heating value of mixture of natural gas with „a” participation and fuel oil is obtained by follow equation:

$$H^{mixt}_{u} = a\, H^{anh}_{u} + (1-a) H_{u\,fuel\,oil} \quad (29)$$

The values of analised pollutants in fuel gas are:

$$C_{SO_2}^{mixt} = a\,C_{SO_2 natural\,gas} + (1-a)C_{SO_2 fuel\,oil} \quad (30)$$

$$C_{NOx}^{mixt} = a\,C_{NOx\,natural\,gas} + (1-a)C_{NOx\,fuel\,oil} \quad (31)$$

$$C_{CO_2}^{mixt} = a\,C_{CO_2 natural\,gas} + (1-a)C_{CO_2 fuel\,oil} \quad (32)$$

$$C_{CO_2 equiv}^{mixt} = a\,C_{CO_2 equiv\,natural\,gas} + (1-a)C_{CO_2 equiv\,fuel\,oil} \quad (33)$$

The results of numerical calculations referring to the production of SO_2, NOx, CO_2 and $CO_{2\ equivalent}$ are presented in *Table 2*.

Table 2

Results of numerical calculation for emissions amounth

Calculated values	Mixture of used fuels					
	Natural gas 100%	Natural gas 90% Fuel oil 10%	Natural gas 70% Fuel oil 30%	Natural gas 50% Fuel oil 50%	Natural gas 30% Fuel oil 70%	Natural gas 10% Fuel oil 90%
H_u^{mixt} [MJ/Nm^3]	34,948	35,491	36,576	37,662	38,747	39,833
V_a^0 [Nm^3/Nm^3]	8,868	9,035	9,368	9,702	10,036	10,369
V_{fg} [Nm^3/Nm^3]	9,874	10,006	10,269	10,532	10,795	11,058
E_{fuel} [GJ]	0,034948	0,035491	0,036576	0,037662	0,038747	0,039833
C_{SO2} [mg/m^3]	0	91,15	273,46	455,75	638,04	820,35
C_{NOx} [mg/m^3]						
- without abatement measures and O_2^{mas}=0%	530,91	552,1	594,52	636,93	679,34	721,75
- with abatement measures (η_{prim}=0,6)	212,36	220,84	237,8	254,77	271,74	288,7
- corrected : O_2^{st}=3%	182,02	189,29	203,83	218,47	232,92	247,46
C_{CO2} [g/m^3]	196,44	204,43	220,42	236,41	252,40	289,22
$C_{CO2,equiv}$[mg/m^3]	199,26	210,96	234,45	257,91	281,37	304,83

Next graphics show the variation of specific amount of analized polluants in terms of mixture of utilised fuels:

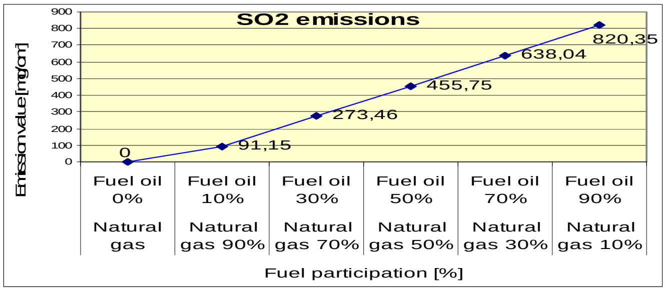

Fig. 2. SO_2 variation at different mixtures of natural gas and fuel oil.

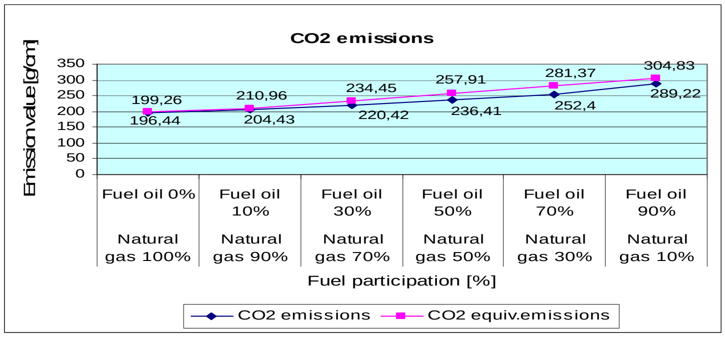

Fig. 3. CO_2 variation at different mixtures of natural gas and fuel oil.

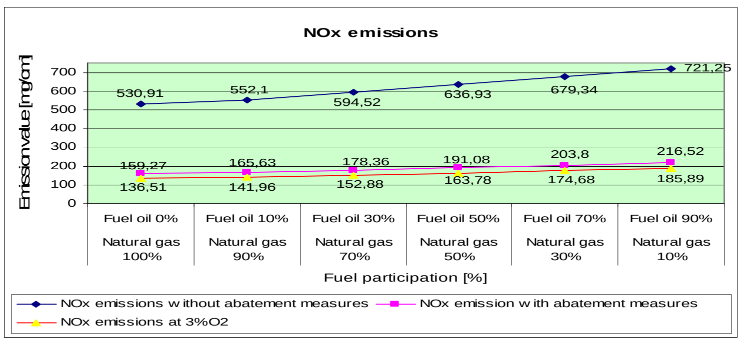

Fig. 4. NOx variation at different mixtures of natural gas and fuel oil.

3.5. Calculation of emissions amount using efficiency of process

This method uses emission factors expressed in units of mass (kilograms of pollutants) per units of energy (MWh). This mode of expression allows the assessment of the pollution level of a power plant based on its production efficiency (a production unit with higher efficiency pollute less compared to one with lower efficiency, to generate the same amount of energy). The indicator is useful as an overall emissions intensity measure of a power plant's electricity and heat generated, and it is easy to calculate.

The characteristics of an cogeneration power plant can be synthetically described by means of the electrical efficiency (η_e), the thermal efficiency (η_t), and the energy utilization factor (EUF), representing the overall cogeneration efficiency :

$$\eta_e = \frac{W_y}{F_y}, \qquad \eta_t = \frac{Q_y}{F_y}, \qquad EUF = \eta_e + \eta_t \tag{34}$$

The emission factor for each electricity unit produced by the cogeneration power plant should be determined as follows:

$$EF_{EL,i} = \frac{3{,}6\,EF_i}{\eta_e} 10^{-3} \quad \text{[kg/MW]} \tag{35}$$

The emission factor for each useful thermal energy unit produced by the cogeneration power plant should be determined as follows:

$$EF_{T,i} = \frac{3{,}6\,EF_i}{\eta_t} 10^{-3} \text{ [kg/MW]} \tag{36}$$

Emission factor calculated taking into account the overall efficiency of cogeneration plant should be determined as follows:

$$EF_{CHP,i} = \frac{3{,}6\,EF_i}{EUF} 10^{-3} \text{ [kg/MW]} \tag{37}$$

For the cogeneration power plants outputs of both electricity and heat exist, but there is only one input amount. The simplest metohod to allocate this input amount between electricity and heat would be to use the *proportionality approach*, which allocates inputs based upon the proportion of electricity and heat in the output. This is equivalent to fixing the efficiency of electricity and heat to be equal. This method has the advantage of simplicity and transparency [8]. According to this principle, if it is denoted by „e" the share of electricity in the total energy produced by the cogeneration power plant, the amount of polluant „i" for electricity produced should be determined as follows:

$$EM_{EL,i} = EF_{CHP,i}\, e\, E_{CHP} \text{ [kg polluant]} \tag{38}$$

The amount of polluant „i" for useful heat produced should be determined as follows:

$$EM_{T,i} = EF_{CHP,i}(1-e)E_{CHP} \text{ [kg polluant]} \tag{39}$$

The amount of polluant „i" for total energy produced by the cogeneration power plant should be determined as follows:

$$EM_{CHP,i} = EF_{CHP,i}\, E_{CHP} \text{ [kg polluant]} \tag{40}$$

The disadvantage, however, is that the proportionality approach usually overstates electricity efficiency and understates heat efficiency. As the efficiency of heat generation is almost always higher than electricity generation, countries with large amounts of district heating will see a higher efficiency (therefore lower emissions intensity) than warmer countries with less district heating.

For avoiding the unrealistic efficiencies a *fixed-heat-efficiency approach* can be used, which fixes the efficiency of the heat part of the generation, and calculates the electricity part of the input accordingly [9]. A typical heat boiler has an efficiency of 90%. The approach uses this as the standard heat efficiency (except when the total cogeneration power plant efficiency was greater than 90%, in which case the observed efficiency would be used). By this method more emissions to the electricity are assigned than when the proportionality approach is used, but that were much closer to those of electricity-only plants.

According to [9], the fixed-heat efficiency approach involves the calculation of emissions using the following equations:

$$EM_i = \frac{EM_{ELE,i} + (EM_{CHP,i} \cdot \%\,from\ ele) + OWNUSE_{ELE,i}}{W_{ELE} + W_{CHP}} \quad (41)$$

$$\%\,from\ ele = \frac{F_{CHP} - (Q_{CHP} / EFF_{HEAT})}{F_{CHP}} \quad (42)$$

$$OWNUSE_{ELE,i} = OWNUSE_i \frac{EL_{output}}{EL_{output} + (HE_{output} / 3{,}6)} \quad (43)$$

4. Conclusions

A cogeneration power plant can allocate emissions based on the input energy, or on the output of each energy stream.

In the first case, emission factors and emissions have been calculated using the useful energy developed by the combustion of fuel. From the calculations it can be seen as emission factors for a cogeneration configuration are dependent on the type of fuel; the resulted emissions are closely related to the fuel type and fuel consumption also.

Flexible fuel supply for cogeneration power plants is very important to meet demand for electricity and heat, where the main fuel (natural gas) is not available. The use of fuel oil in different proportions instead of natural gas affects the emission factors and the resulting emissions, but the need to ensure security of supply imposes their use. Calculations show that the amount of all analyzed pollutants resulting from the combustion grows with increasing the percentage of fuel oil used (see *Table 2* and *Fig.1, 2, 3*).

The use of combustion control techniques (primary measures for NOx emissions abatement such low NOx burners, staged air supply, over fire air and flue gas recirculation) is very important in this case and less costly than post-combustion control methods; as we can see (*Table 2*), the use of such techniques keeps the NOx emission values within limits of environmental regulations.

The SO_2 emissions depend on proportion of sulphur in the elemental analysis of the fuel. The use of fuel oil with low proportion of sulphur contents is needed because the use of expensive abatement technologies such flue gas desulphurisation processes to keep SO_2 emission values within limits of environmental regulations brings to decrease of cogeneration benefits.

The efficiency method allocates the emission factors and emissions based on the efficiencies of thermal energy and electricity production. As a result, the emissions per unit of energy produced (electricity or heat) can vary from year to year, depending on the generation mix. In order to calculate this ratio of emissions, the outputs (and thus the emissions) of cogeneration power plants are allocated between electricity and heat. It was assumed that heat generation within cogeneration power plants had 90% efficiency (or higher if the total combined heat and power plant efficiency was higher) and the electricity output was calculated accordingly. But this would not give a true comparison between countries; if one allocates a high efficiency to the heat part of cogeneration, this decreases the efficiency of the electricity part and thus increases electricity's emissions intensity.

Emission factors provide indications of the appropriateness of different fuel use. Future gas supply arrangements are expected to be significantly less flexible. If greater oil flexibility were to occur, then the emissions could be expected to rise, as well as the variable cost of electricity. From this point of view, cogeneration becomes an option due to the high conversion efficiency of fuel.

Notations and measure units

EF_i represents specified emission factor for polluant „i" (SO_2,NOx,CO_2,CH_4,N_2O) [g/GJ];
$C_{S\ fuel}$ - fuel sulphur content in fuel [kg/kg];
α_s - sulphur retention in ash [%];
H_u - lower heating value of fuel (fuel oil or natural gas)[MJ/kg];
E_{fuel} - energy from fuel [GJ];
H^u_{anh} - lower heating value of dry natural gas (given value)[MJ/kg];
w_t^i – fuel oil moisture content [%];
d - humidity (d = 15 g/Nm^3 natural gas);
$C_{N\ fuel}$ - nitrogen content in fuel (in mass nitrogen/mass fuel) [kg/kg];
$C_{volatiles}$ - fuel content of volatiles (in mass volatiles/mass fuel) [kg/kg];
$C_{C\ fix}$ - fixed carbon in fuel (in mass carbon/ mass fuel) [kg/kg] ;
$C_{NO\ thermal}$ - content of thermal-NO formed (in mass pollutant/mass flue gas) [kg/kg];
γ - fraction for thermal-NO formed, expressed as a fraction of NO_{fuel} [%].
η_{sec} - reduction efficiency of secondary measures [%];
β - availability of secondary measures;
C_{NO2} - nitrogen dioxide in flue gas (in mass pollutant/volume flue gas) [mg/m^3];
V_D - dry flue gas volume (in volume flue gas/mass flue gas) [m^3/kg];
FC - fuel consumption (1 kg fuel oil *or* 1 Nm^3 dry natural gas);
$C_{NOx,x}$ - the value of NOx for „x" load ;
$C_{NOx,100}$ - the value of NOx for full load of boyler;
c - coefficient according as fuel type (0,85 for coal, 0,75 for fuel oil and 0,50 for natural gas);
L - boyler load (seized between 50% and 100%).
$C_{C\ fuel}$ - carbon content of fuel (in mass C/mass fuel) [kg/kg];
ε_C - fraction of carbon oxidised (defined as the main part of carbon which is oxidised to CO2);
$C_{CH4\ fuel}$ - methane content of fuel (in mass CH_4/mass fuel) [kg/kg];
ε_{CH4} - fraction of methane oxidised (defined as the main part of methane which is oxidised to CO2 and H_2O; small amounts of methane may remain unoxidised);

ε_{N2O} - fraction of nitrogen oxidised (defined as the main part of nitrogen which is oxidised to N_2O);
W_y - electricity produced by the cogeneration power plant „y" [MWh];
Q_y – useful heat produced by the cogeneration power plant „y" [MWh];
F_y – total fuel consumption for the cogeneration power plant „y" [MWh].
$EF_{EL,i}$ - the emission factor for polluant „i", for each electricity unit produced by the cogeneration power plant [kg/MW];
$EF_{T,i}$ - the emission factor for polluant „i", for each useful thermal energy unit produced by the cogeneration power plant [kg/MW];
$EF_{CHP,i}$ - the emission factor for polluant „i", for each energy unit produced by the cogeneration power plant [kg/MW];
$EM_{EL,i}$ - the amount of polluant „i" corresponding to the electricity produced by the cogeneration power plant [kg polluant];
E_{CHP} – total energy produced by cogeneration power plant[MW].
$EM_{T,i}$ - the amount of polluant „i" corresponding to the useful heat produced by cogeneration power plant [kg polluant];
$EM_{CHP,i}$ - amount of polluant „i" corresponding total energy produced by cogeneration power plant [kg polluant];
EM_i - the amount of polluant „i" [kg polluant];
$EM_{ELE,i}$ - amount of polluant „i" from electricity only plant [kg polluant];
$EM_{CHP,i}$ - amount of polluant „i" from cogeneration power plant [kg polluant];
$OWNUSE_i$ - amount of polluant „i" from own use in electricity, cogeneration and heat plant [kg polluant];
W_{ELE} - total electricity output from electricity only plant [MW];
W_{CHP} - total electricity output from cogeneration power plant [MW];
EL_{output} - total electricity output from electricity and cogeneration power plant [MW];
Q_{CHP} - useful heat output from cogeneration power plant [MW];
HE_{output} - total heat output from cogeneration and heat plant [MJ];
F_{CHP} - energy imputs to cogeneration power plant [MW];
EFF_{HEAT} - heat efficiency: is assumed to be 0,9, except when the efficiency of cogeneration is higher than 90%, in wich case it is set at the higher value.

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