Hindawi Publishing Corporation
Research Letters in Ecology
Volume 2008, Article ID 236907, 4 pages
doi:10.1155/2008/236907

Research Letter

On Some New Indicators for the Energo-Ecological Assessment of Thermo-Power Plants Operation

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Received 5 March 2008; Accepted 11 April 2008

Recommended by Pavlos Kassomenos

The authors offer a critical analysis of pollution indicators currently applied for the ecological assessment of the thermo power plant's operation. They forward new "energo-ecological" indicators to highlight both the qualitative aspect of polluting emissions and their quantitative aspect, by relating their concentration in the flue gases purged into the atmosphere to the energy produced during the same interval. The application of these indicators contributes to the attenuation of the global warming phenomenon and to the protection of the world's resources of fossil fuels.

1. INTRODUCTION

It is known that fact that a major part of the consumed primary energy comes from fossil fuels. The burning of these fuels result in polluting emissions purged into the atmosphere, that is, noxious gas emission, toxic for animal and plants (nitrogen oxides and sulphur oxides, expressed as SO_2 [1]), and greenhouse gases (GHGs). When burning fuels, the latter (GHGs) are the nitrogen oxides (NO_x) and the carbon dioxide (CO_2).

In the past years, one took into account especially the toxic effect of polluting emissions and consequently the international norms in this field referred to the limitation of these emissions (SO_2 and NO_x) [2].

During the last period, especially after 2000, one has remarked worrying climatic changes. They are mainly due to the increase of the GHG emissions. Under these circumstances, one is currently emphasizing the reduction of the GHG emissions, among which, as we know, CO_2 has a high percentage.

Considering all the above, it results that in the analyses regarding polluting gas emissions, besides NO_x and SO_2 (contained in the present norms for their limitation in the flue gases), we should also consider the CO_2 emissions. On the other hand, in the interest of reducing the total quantity of such emissions for avoiding the excessive global warming and for preserving mankind's reserves of classic fuels, it has become important to consider the polluting emissions related to the energy produces during this process, in terms of their ratio.

We will analyze this issue in detail, with application to the field of thermo power plants(TPPs).

2. THE OPPORTUNITY OF CONSIDERING THE NET EMISSION FACTOR

At present, in the EU countries, for the limitation of emissions of certain pollutants into the air from large combustion plants, we apply "*Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001*" [2]. If we refer to the polluting gas emissions—sulphur dioxide (SO_2) and nitrogen oxides (NO_x)—the respective directive focuses on the concentration of these gases. The dimension of these emissions will be thus [mg/Nm^3].

We consider that the limitation of pollutants according to [2] was appropriate in the past, when the focus was laid on the concentration of polluting gases in the flue gases, and when we considered as most important the toxic influence of these gases on animals and plants. But at present, in the light of the previous chapter (the greenhouse effect of polluting emissions), we think that the limitations of TPP's polluting emissions into the air should also take into account

the quantitative aspect of the phenomenon. In other words, these limitations must lead to the emission of more reduced quantities, as reduced as possible, of pollutants related to the quantity of useful electric energy and/or thermal energy the TPP in question produces. These can be solved by considering the ratio of the concentration of the polluting gases emissions per energy produced simultaneously with the respective emissions.

This approach is not completely unheard of; it was encountered in the case of the norms for the polluting emissions from motor vehicles [3–5].

We should also point out that CO_2 is the most important greenhouse gas (GHG) and consequently the limitations of polluting emissions, besides NO_x and SO_2, will have to refer also to the carbon dioxide.

The following discussion will be focused on the development of the idea contained in the title of the present chapter.

For this purpose, as a first step, we use the notion of "*raw emission factor*." We noted it REF and, for the three polluting gases, it is given by the following relations:

$$\begin{aligned} \mathrm{REF}_c &= V_g \cdot (\mathrm{CO}_2)/Q_i \ [\mathrm{kg/kJ}], \\ \mathrm{REF}_n &= V_g \cdot (\mathrm{NO}_x)/Q_i \ [\mathrm{kg/kJ}], \\ \mathrm{REF}_s &= V_g \cdot (\mathrm{SO}_2)/Q_i \ [\mathrm{kg/kJ}]. \end{aligned} \tag{1}$$

In the above relations, V_g is the volume of flue gases resulted from the combustion of one kgf of fuels and has the dimension [Nm^3/kgf]; kgf is the measuring unit for the fuel mass (f-fuel). (CO_2), (NO_x), and (SO_2) represent the concentration of polluting emissions in the burning gases, and they are described thus by [kg/Nm^3]. Q_i is the inferior thermal power of the fuel and is measured in [kJ/kgf].

The emission factors REFs give indications about the "ecological characteristics" of a fuel.

In order to further analyze the issue we focus on the following. We divided the conventional fuels into four major categories and we retained for them the average values of REFs, as listed in Table 1. Moreover, the average values of Q_i and V_g were also given. Table 1 also shows the values of the V_g/Q_I ratio.

The last three characteristics will be used below. These values were taken from the literature. In order to take the second step toward the reaching of the set goal, we introduce the notions of "*net emission factor*" NEF, expressed as depending of the REF values starting from relations (1), and so

$$\begin{aligned} \mathrm{NEF}_c &= \mathrm{REF}_c/\eta = V_g(\mathrm{CO}_2)/\eta Q_i \ [\mathrm{kg/kJ}], \\ \mathrm{NEF}_n &= \mathrm{REF}_n/\eta = V_g(\mathrm{NO}_x)/\eta Q_i \ [\mathrm{kg/kJ}], \\ \mathrm{NEF}_s &= \mathrm{REF}_s/\eta = V_g(\mathrm{SO}_2)/\eta Q_i \ [\mathrm{kg/kJ}]. \end{aligned} \tag{2}$$

In the above relations, η represents the general efficiency of an TPP, that is, the ratio of the useful energy delivered by the energetic installation per thermal energy contained in the fuel.

By useful energy ($\eta \cdot Q_i$), we understand the electric and/or thermal energy delivered at the terminals of the electric generator or/and at the interface point of the installation with the system of thermal energy use. We neglected the internal consumptions of TPPs, such as those for the preparation and manipulation of fuel up to its introduction into the installation of the boiler, those for the circulation of the cooling water, and so forth.

The consideration of the NEFs indicators fully satisfies the present need to analyze the TPPs operation in a complete manner, that is, under the aspect of the atmospheric pollution in correlation with the produced useful energy. Thus, the NEFs indicators have an energo-ecological character.

For an TPP, it is important that during its operation one should obtain emission indicators as reduced as possible. This can be achieved, on the one hand, by using high-quality fuel, especially hydrocarbons (see the REFs values in Table 1). On the other hand, the high values of the TPP's general efficiency also result in small values of NEF.

The emissions of nitrogen oxides and sulphur oxides, that is, (NO_x) and (SO_2), may be reduced, in their turn, as shown above by means of special methods or installations characterized by the efficiency σ. The methods of CO_2 capture are also characterized by their own efficiency. Considering all this, the NEFs emission factors may be expressed by the following relations:

$$\begin{aligned} \mathrm{NEF}_c &= 3600 V_g (1-\sigma_c)(\mathrm{CO}_2)/\eta Q_i \ [\mathrm{kg/kWh}], \\ \mathrm{NEF}_n &= 3600 V_g (1-\sigma_n)(\mathrm{NO}_x)/\eta Q_i \ [\mathrm{kg/kWh}], \\ \mathrm{NEF}_s &= 3600 V_g (1-\sigma_s)(\mathrm{SO}_2)/\eta Q_i \ [\mathrm{kg/kWh}]. \end{aligned} \tag{3}$$

Depending on the system applied for the reduction of the SO_2, NO_x, and CO_2 emissions into the atmosphere, their efficiency may have values between 0.5 and 1.0.

Compared to the analysis of TPPs depending on the polluting gas emissions related to the quantity of the flue gases (measured in [kg/Nm^3]), their analysis depending on NEFs factors (measured in [kg/kWh]) has the following advantages.

(i) One may highlight the TPP technical level as regards the technology applied for the process of energy production, the operational state of the technical equipment as well as the manner of its exploitation.

(ii) One may identify the elements upon which the TPP owner may intervene, in the sense of improving the NEFs values.

(iii) By introducing certain norms of NEFs limitation, one may stimulate the TPPs investors to apply certain technological diagrams/flow charts and to take some technical measures of global interest for the entire mankind. Thus, obtaining values of NEFs as small as possible results in reduced quantities of polluting gases, and thus of GHG compared to the produced useful energy. This leads to the reduction of the classic fuels' consumption. The issue is of great importance also at the global level, considering that their exhaustion is predicted to happen in a very short historical time.

Table 1

	Lignite	Pit coal	Fuel oil (with $S \leq 1\%$)	Natural gas
$10^6 \cdot \mathrm{REF}_c$ [kg/kJ]	105	90	72	50
$10^6 \cdot \mathrm{REF}_n$ [kg/kJ]	0.24	0.43	0.245	0.15
$10^6 \cdot \mathrm{REF}_s$ [kg/kJ]	3.32	2.06	0.459	—
Q_i [kJ/kgf]; [kJ/Nm^3]*	8000	13000	42600	35700*
V_g [Nm^3/kgf]; [Nm^3/Nm^{3}f]**	3.353	4.417	11.308	9.983**
$10^4 \cdot V_g/Q_i$ [Nm^3/kJ]	4.191	3.400	2.654	2.796

Table 2

Fuel	$\eta_{\min}$
Lignite	0.44–0.75
Pit coal	0.45–0.80
Fuel oil	0.48–0.85
Natural gas	0.48–0.85

The values of the general efficiency η are of remarkable importance for the values of NEFs.

The next section will further discuss this issue.

3. THE GENERAL EFFICIENCY OF TPPS

It is known that the general efficiency η occurring in the relations for NEFs in Section 2 depends on a series of constructive and operational factors.

All this considered and keeping in mind the stringent necessity of intensive reduction, in the near future, of the polluting gases emissions of TPPs; we show in Table 2 the minimum values of the efficiencies η that can be considered in the next period for the four categories of fuels.

The minimum values of the efficiencies presented in Table 2 are specific to some simple thermodynamic cycles (the Rankine cycle with steam condensing turbine) and to some ordinary parameters of fluids (steam, gas) at the turbine entrance. Increased values of the efficiency are obtained in the case of the thermodynamic cycles that are superior from a technical point of view (with cogeneration, combined gas and steam cycles) and respective of some very high parameters of those fluids (i.e., ultrasupracritical parameters in steam case).

Based on the above elements, we consider that it is high time the provisions of [2] be replaced by others, based on the *net emission factors—NEFs)*. Only then TPPs' emissions of polluting gases can be monitored under the aspect of concentrations (toxic effect) but also from the perspective of the total quantity of such gases (especially GHG).

This last aspect is extremely important, considering the high risk of major climactic changes as well as the rapid exhaustion of classic fuels.

4. CONCLUSIONS

From all the above we may draw the following important conclusions.

4.1. The necessity of new regulations for TPPs atmospheric emissions

The concentration (expressed in [mg/Nm^3]) of the atmospheric emissions of polluting gases resulted from the operation of thermo power plants (TPPs) is no longer an indicator enabling us to monitor two major challenges facing mankind today: global warming and rapid exhaustion of classic fuel reserves. This has become stringent as the present regulations regarding the respective concentrations [2] refer only to NO_x and SO_2 and not to CO_2 which has an essential role in the creation of the greenhouse effect.

4.2. The importance of the net emission factors

The net emission factors (NEFs) expressed in [kg/kWh] analyzed in the present paper solve the acute problem of monitoring the emissions of all polluting gases—NO_x, SO_2, and CO_2—in relation with the electric and/or thermal energy produced by the TPPs along with the respective emissions. In these indicators, a very important part is played by the general efficiency of the analyzed TPP. In order to get better values of these indicators (as reduced as possible NEFs), the owners of TPPs will be forced to apply technologies leading to smaller concentrations of the polluting emissions, but also to the obtaining of electric and/or thermal energy at the highest possible efficiency.

Consequently, one can thus automatically reach the global interest desiderata of reducing the total quantity of polluting gases (especially greenhouse gases) and of a more and more rational use of the world's classic fuels resources.

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