

Short communication

## Evaluation of the physical dew point in the economizer of a combined cycle burning natural gas

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### Abstract

Natural gas contains a considerable percentage of hydrogen, so is obvious to expect an amount of water vapour in its combustion exhaust gases, which would raise the dew point temperature. That means a higher speed of corrosion over the whole exposed physical area, which could represent a serious risk of breakdown, especially in pressurized hot-water equipments. In this work, a new methodology for determining the physical dew point inside a economizer depending on the fuel type burned (in this case is natural gas) has been developed. The calculation of the total amount of condensed water has also been carried out as well as the localization of the area where this condensation occurs. Acid dew point has not been taken into account here although exhaust gases are acidic, due mainly to the low sulphur content which is almost undetectable when burning natural gas, but it will be performed in a later study coming soon.

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### 1. Introduction

The natural gas contains a considerable percentage of hydrogen, in terms of mass, in its composition. Thus, a high water partial pressure in the combustion exhaust gases is expected, which will tend to raise the physical dew point. However, the formation of the acid dew point in the combustion of natural gas is not taking into account, due mainly to the fact that the habitual content of sulphur in mass, in the composition is almost void [1,2]. Only the odorizer, added to detect the gas, contains sulphur but in such small quantities, that partial pressure of  $\text{SO}_x$  in the combustion exhaust gases turns out to be practically undetectable.

Condensate of the combustion products for the natural gas presents initially a pH of about 3 (clearly validated in the daily practice of the power plant of reference), so effectively it is an acid flow. This acid value for the pH of the

condensed flow is mainly due to the formation of carbonic acid but also to nitric acid.

On one hand, the carbonic acid, which is very volatile, is formed because of the closer contact existing between the water vapour and the carbon dioxide in the combustion exhaust gases, with an acidity constant of  $4.45 \times 10^{-7}$ . The formation route is



On the other hand, the formation of nitric acid is mainly due to the  $\text{NO}_x$  of the combustion exhaust gases. It is obtained by synthesis from the pentoxide of di-nitrogen, mixing it with water, according to the following reaction:



Besides, in the combustion exhaust gases, the major quantity corresponds to nitric oxide (NO) and in minor quantity  $\text{NO}_2$ . The NO does oxidize rapidly and form  $\text{NO}_2$  which also continues the oxidizing process to  $\text{NO}_3^-$  (acid aerosol) or directly to nitric acid, which can be dissociated itself completely in water.

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## Nomenclature

CO <sub>2</sub>	carbon dioxide
$E$	thickness of the tube (mm)
GCV	gross calorific value (kJ/N m <sup>3</sup> fuel)
$L$	length of the economizer (m)
LCV	lower calorific value (kJ/N m <sup>3</sup> fuel)
$m$	mass (kg)
$M$	molecular weight (g)
NO <sub>2</sub>	nitrogen dioxide
NO <sub>x</sub>	nitrogen oxides
$P$	barometric pressure (bar)
PDP	physical dew point (°C)
HR	relative humidity (%)
SO <sub>3</sub>	sulphur trioxide
SO <sub>x</sub>	sulphur oxides
$V$	volume (N m <sup>3</sup> )
$x$	steam quality (kg H <sub>2</sub> O/kg dry air)
$y$	amount of water vapour (N m <sup>3</sup> /m <sup>3</sup> fuel)

### Greek symbols

$\psi_i$	number of moles of each component $i$ of the fuel (mol/N m <sup>3</sup> )
$[\Omega]_{\text{O}_2(\text{ex})}$	excess of oxygen (%)

$[\Phi]_{\text{H}_2\text{O}}$	coefficient of water vapour in the total exhausts gases (0/1)
$\theta$	temperature (°C)
$\phi$	diameter (mm)

### Subscripts

(a)	air
(amb)	relative to the ambient
(cond)	relative to the condensed phase
(da)	relative to the dry air
(dg)	relative to the dry gases
(ex)	relative to excess
(f)	relative to the fuel
(s)	relative to the saturation
(i)	relative to the inlet
(o)	relative to the outlet
(p)	relative to partial
(t)	relative to stoichiometric
(tg)	relative to the total gases
(v)	relative to the vapour

The result for the pH is that though initially it is of the order of 3 (due to both mentioned acids), it stays finally with a pH of the order of 6, once the carbonic acid has been completely eliminated. Evidently this means a process of acid corrosion although in this paper we refer mainly to the point of physical dew point, leaving for another later article coming soon the consideration of the acid dew point.

For example, combined cycles are usually designed to burn “gas–oil” as alternative fuel, which is a very high quality fuel and usually is expressly manufactured for this use [3]. Nevertheless, the habitual content of sulphur, in its composition, is about 0.05% and in consequence, the acid dew point should be considered. For such sulphur content, the partial pressure of SO<sub>3</sub> will be reached at temperatures closed to the acid dew point formation, that is about 37.78 °C [4]. The design of combined cycles includes recirculation pumps in the economizer, so when burning gas–oil, these pumps would start working and the water temperature in the economizer would be settled up automatically in 74 °C, clear away in this way any possibility of acid dew point formation in the whole structure of the economizer [5].

It is necessary to take into account that some water must be injected to the combustion process, in order to minimize NO<sub>x</sub> formation [6], which obviously contributes to raise the physical dew point.

Nevertheless, an amount of slightly less than 1 kg of water vapour per kilogram of fuel is generated in the combustion of gas–oil, due to the combustion of the hydrogen contained in the composition, whereas the combustion of natural gas, more than 2 kg of water vapour per kg of fuel

are generated, what means more than 90% of the water vapour in the combustion exhaust gases. It can be deduced, that its partial pressure, burning natural gas, always will be considerably higher to the same one from the gas–oil combustion [7,8] and in consequence, only the physical dew point formation, will be taken into account.

The possibility of reaching the physical dew point somewhere in the surface of the economizer, means a higher speed of corrosion, decreasing in this way the thickness of the tube bundle, working at a pressure of about 5.7 bar [9], which means a serious risk of a general collapse. In this work, a deep study has been carried out inside the economizer from a power plant of reference, in order to develop a new methodology for predicting the physical dew point formation in combined cycles burning natural gas, depending on different combustion conditions and also suitable for other fuels.

## 2. Aims and methodology

The establishment of a methodology for the evaluation of the dew point temperature of the combustion exhaust gases is the principal aim of this study. On one hand, the stoichiometric air volume is needed for the final evaluation of the volume of combustion exhaust gases. On the other hand, the theoretical air mass is also necessary for a later evaluation of the total mass of dry air for the effective combustion, which besides is necessary for the dampness of the air oxidizer evaluation [10,11], both in volume and mass fractions.

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