Temperature of Combustion Gases from Natural Gas

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Abstract
Combustion gases from natural gas are mixture of five individual gases. They origin is the combustion of natural gas, ten individual gases with atmospheric air, five individual gases. Authors present in their works thermodynamic parameters of this combustion gas with help of thermodynamics of gas mixtures. In this paper they present their method of determination of temperature of hot combustion gases from natural gas 2010, and one concrete example with numerical results.

Key words: *Natural gas, Combustion gases, Temperature of gas mixtures*

Introduction

Combustion gases from natural gas are mixture of five individual gases, nitrogen, oxygen, carbon dioxid, argon and water vapour. Their source is combustion of natural gas, which is mixture of ten hydrocarbons and of atmospheric air, which is mixture of five individual gases, as source of oxygen. All this gases have parameters in dependence of temperature in different exponential dependences. Authors used in their work exact values of its thermodynamic parameters from thermal tables in (RAZNJEVIČ, 1969).
In professional literature is thermodynamic of combustion gas nearly only analysed with thermodynamics of one ideal gas. Calculations are therefore not exact.
Authors elaborated therefore their method for exact parameters of combustion gases of gas fuels with thermodynamic of gas mixtures and with using of exact values of thermodynamic parameters, as in their work (VITÁZEK-HAVELKA, 2008).
In this paper they present one part of their method for destination of exact temperature of hot combustion gas

Material and methods

Authors appreciate in this paper combustion gas of natural gas which was delivered by SPP a.s. in Bratislava in the year 2010. SPP presents every months in Internet (www.spp.sk, 2010) composition of natural gas, delivered in Slovakia and some basic properties from laboratory specimens.
Authors used in their work average values of these statements calculated for the whole year 2010 presented in their work (VITÁZEK-HAVELKA, 2011).

Authors used exact values of thermodynamic parameters of individual gases from tables in (RAŽNJEVIČ, 1969), where are tables of enthalpy of gases for temperatures from 0°C to 3000°C. They divided this temperature span in four sections:
0 ÷ 100°C for climatisation and drying of seed materials,

100 ÷ 500°C for drying of cereal grains and other agricultural products for consum,

500 ÷ 1000°C for drying of food materials, lucerne, hay and sim..,

1000 ÷ 2400°C for boilers and heat exchangers.

Authors derived in every section with linear regression linear relations for enthalpy:

Authors used in this paper their stechiometric parameters of natural gas 2010 from their work (VITÁZEK-HAVELKA, 2011).
Authors analyse in their work an indefinite establishment with thermal efficiency of burning η_h and with air surplus coefficient α.
Authors consider combustion gases as mixture of stechiometric combustion gases and of air surplus m_p with surplus coefficient α:

$$a = \frac{m_{iv} + m_p}{m_{iv}} \tag{1}$$

Authors describe mass quantities relations of individual gases for mass of natural gas m_{ng} = 1 kg.
Mass quantities of individual gases in combustion gas are described with relations:

Nitrogen N_2	$m_{N2} = m_{iv} \,.\alpha \,.\, \sigma_{aN2} + \sigma_{ngN2}$	(2)
Oxygen O_2	$m_{O2} = m_{iv} \,.\, (\alpha - 1) \,.\, \sigma_{aO2}$	(3)
Carbon dioxide CO_2	$m_{CO2} = m_{iv} \,.\, \alpha \,.\, \sigma_{aCO2} + \Delta m_{CO2} + \sigma_{ngCO2}$	(4)
Argon et high. Ar	$m_{Ar} = m_{iv} \,.\, \alpha \,.\, \sigma_{aAr}$	(5)
Water vapour H_2O	$m_w = m_{iv} \,.\, \alpha \,.\, x_o + \Delta m_w$	(6)

Whole mass of combustion gases from 1 kg of natural gas is:

$$m_{cs} = \sum m_{is} \tag{7}$$

Enthalpy of combustion gases calculated from basic temperature 0°C, without any latent heat, is:

$$i_s = \sum s_{si} \,.\, i_{si} = \sum \frac{m_{si} \,.\, i_{si}}{m_{cs}} \quad \text{kJ/kg} \tag{8}$$

The function $i = f(t)$ is not linear, but exponential. Authors therefore divided the whole temperature area in mentioned temperature sections. They derived in every section with linear regression this linear relation:

$$i = a + b.t \quad \text{kJ/kg} \tag{9}$$

In all sections the value of coefficient of regression is better as 0.999.

Enthalpy of combustion gases calculated with this table values, is:

$$i_{st} = \sum s_{si} \,.\, (a_{si} + b_{si} \,.\, t_s) = \sum \frac{m_{si} \,.\, (a_{si} + b_{si} \,.\, t_s)}{m_{cs}} \quad \text{kJ/kg} \tag{10}$$

Enthalpy of combustion gases, calculated with heat value q_n of natural gas is sum of increase of enthalpy Δi_1 of combustion gases between ambient temperature t_o and temperature of hot combustion gases t_s, and of complement of enthalpy Δi_o for temperature section from t_o to 0°C:

$$i_{st} = \Delta i_1 + \Delta i_0 = \frac{q_n \,.\, h_h}{m_{cs}} + \sum \frac{m_{si} \,.\, c_{pi} \,.\, t_0}{m_{cs}} \quad \text{kJ/kg} \tag{11}$$

Authors derived following relation for calculation of the temperature of hot combustion gases:

$$i_{sq} = \sum \frac{m_{si} \,.\, (a_{si} + b_{si} \,.\, t_s)}{m_{cs}} \quad \text{kJ/kg} \tag{12}$$

From this eq. they derived final relation for temperature of hot combustion gases:

$$t_s = \frac{i_s \,.\, m_{cs} - \sum m_{si} \,.\, a_{si}}{\sum m_{si} \,.\, b_{si}} \quad \text{°C} \tag{13}$$

Results and Discussion

Example
Given values:
Atmospheric air: temperature t_o = 15°C, pressure p_a = 100 kPa, relative humidity φ = 60%
Mass concentrations of individual gases selected from (CHYSKÝ, 1977)
Specific moisture, from i-x diagram of wet air x_o = 6.5 g/kg

Establishment: Thermal efficiency of the burner η_h = 98%
Air surplus coefficient α = 1.1

Natural gas 2010, from (VITAZEK-HAVELKA, 2011)
Stechiometric mass of dry air for 1 kg of natural gas m_{iv} = 16.89 kg
With combustion of 1kg of natural gas we obtain new gases:

Carbon dioxide	Δm_{CO2}	= 2.7086 kg
Water vapour	Δm_w	= 2.1866 kg
Heat value of natural gas 2010	q_n	= 48 883 kJ/kg

From 1 kg of burned natural gas remain inert gases:

Carbon dioxide	σ_{ngCO2}	= 0.0047 kg/kg
Nitrogen	σ_{ngN2}	= 0.0139 kg/kg

Temperature of combustion gases will be in the area 1000÷2400°C.

Authors' therefore used relations of linear regression of enthalpy in the temperature section 1000÷2400°C:

Nitrogen	$i_{N2} = 1.2778.t - 170.32$	kJ/kg	r = 0.99975	(14)
Oxygen	$i_{O2} = 1.178.t - 158.73$	kJ/kg	r = 0.99992	(15)
Carbon dioxide	$i_{CO2} = 1.3595.t - 245.7$	kJ/kg	r = 0.99995	(16)
Argon + high.	$i_{Ar} = 0.523.t$			(17)
Water vapour	$i_w = 2.2574.t - 735.09$	kJ/kg	r = 0.99963	(18)

Calculated mass quantities of individual gases for combustion of 1kg natural gas:

Nitrogen	m_{N2} = 14.069	kg/kg
Oxygen	m_{O2} = 0.3909	kg/kg
Carbon dioxide	m_{CO2} = 2.9511	kg/kg
Argon +	m_{Ar} = 0.0093	kg/kg
Water vapour	m_w = 2.2574	kg/kg
Whole mass	m_{cs} = 19.6777	kg/kg

Introduction in the relation for combustion gas enthalpy:

$$i_{st} = \Delta i_1 + \Delta i_0 = 2\,434 + 16.6 = 2\,451.6 \quad \text{kJ/kg} \tag{19}$$

$$\sum m_{si}.a_{si} = -\ 4\,840 \tag{20}$$

$$= 28.81 \tag{21}$$

And final relation for temperature of combustion gases:

$$t_s = \frac{2451.6\,.\,19.67\ +4840}{28.81} = 1841.9 \quad {}^{o}\text{C} \tag{22}$$

Presented method describes only one thermodynamic process, process of burning of natural gas, in which mixture of natural gas and atmospheric air is transformed in mixture of combustion gases with effective output of heat.
Authors are not studying the effectivity of this process of burning. This phenomenon they express only with one coefficient of thermal effectivity of the burner η_h .
As a result of using exact thermodynamic parameters from thermal tables is the possibility to calculate exact values of enthalpy and temperature of combustion gases. This method is above first established for modelling of combustion of natural gas in establishment with prescribed conditions.
Presented method is time consuming. Therefore for greater amount of calculations it is advantageous to use a computer with pertinent computer program.

Conclusion

Presented method enables to calculate exact values of temperature and other thermodynamic parameters of combustion gases from natural gas.
Authors use this presented system as part of a computer program in Q-Basic for calculation of all desired thermodynamic parameters of combustion gases from gas fuels.
Authors present this paper as example of research and development work in their school activity.

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