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Study of the Consequences of Changes in the Composition of Natural Gas

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Abstract: The following study deals with the consequences of the change of some components of natural gas due to a change of supplier. This is mainly an increase in the amount of ethane, at the expense of methane. This is associated not only with a change in higher calorific value and lower calorific value, but also with a changed ratio of flue gas components, is the amount of CO_2 generated. The heat released during combustion can be expressed either by higher calorific value (HCV) or lower calorific value (LCV). HCV is higher than the LCV by the condensation heat of the water vapor contained in the flue gas.

Key words: Natural gas; chemical composition; stoichiometric equations; higher calorific value; lower calorific value; flue gases

1. Introduction

Natural gas (NG) has several significant advantages that predispose it to use in all areas of industry. One of these advantages is its chemical composition, which burdens the environment with the least of all fossil fuels. The main reason for this study is the possible transition from Transit NG to Norwegian NG. However, when changing the supplier, it is necessary to recalculate the consequences of the change of individual components of the NG, which may change not only the amount of flue gases generated, but also the lower calorific value.

This study was created for the needs of industrial companies of the VÍTKOVICE group, as a methodological guide for the needs of setting the parameters of gas appliances, especially from the point of view of changing the amount of combustion air and changing the amount of flue gases per unit of fuel. From an energy point of view, the lower calorific value will also increase, but this heat gain is partially degraded by the increased demands of Norwegian gas on the amount of combustion air. The study also includes a calculation table where the amount of individual components can be changed.

2. Basic Physical Properties NG

Natural gas is a mixture of gaseous hydrocarbons. Its main component is methane (up to 98 %). Due to the high proportion of methane, natural gas can be described as an ecological fuel, as combustion with oxygen produces one molecule of CO_2 and two molecules of water. Its combustion represents a lower burden on the environment compared to petrol, diesel or Propane-Butane (LPG). Natural gas is a natural flammable gas and is odorless, so during its distribution, so-called odorization is performed, is odorous gases are added so that natural gas can be smelled in the air in a concentration

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greater than 1 %.

- *Density 0.7 kg·m^{-3} (dry gas),*
- *400 kg·m^{-3} (liquid),*
- *Ignition temperature 650 °C,*
- *Adiabatic flame temperature approx. 2 000 °C,*
- *Lower calorific value approx. 35 MJ·m^{-3},*
- *Lower explosion limit 4.4 %,*
- *Upper explosion limit 15 %.*

The main and important advantage of incineration is the ecological purity and easy distribution. During the combustion of natural gas, all pollutants monitored today are reduced, both nitrogen oxides, carbon monoxide, carbon dioxide, as well as solid particles and carcinogens. Another advantage is safety, which is based on some properties of natural gas. Natural gas is lighter than air or diesel, petrol and LPG and therefore does not collect anywhere and disperses in the surrounding atmosphere.

2.1 Chemical composition of NG

Natural gas is composed mainly of saturated hydrocarbons, generally described by the formula C_xH_y, while the composition of individual components depends on the location of discovery. The dominant component is always methane (CH_4), other saturated hydrocarbons are less represented, while each hydrocarbon has a different calorific value during combustion.

Higher and lower calorific values of fuels are empirically determined values of the amount of energy released by perfect combustion of a unit amount of fuel, while in the case of higher calorific value the heat gain from condensation of water vapor in the flue gas is considered. It is clear from the following table that the more complex the molecule, the higher its energy content and therefore the higher the amount of oxygen for combustion.

Table 1: Higher and lower calorific value of saturated hydrocarbons

Natural gas component	Higher calorific value Q_{si}		Lower calorific value Q_{ii}	
	(kJ·m^{-3})	(kWh·m^{-3})	(kJ·m-^{3})	(kWh·m^{-3})
Methane CH_4	38 819	10.783	35 883	9.968
Ethane C_2H_6	70 293	19.526	64 345	17.874
Propane C_3H_8	101 242	28.123	93 215	25.893
Butane C_4H_{10}	134 061	37.239	123 810	34.392

The following table shows the declared amount of natural gas components from the four main suppliers.

Table 2: Composition of NG of various suppliers

Natural gas component	Volume fraction of the component in natural gas (%)			
	Transit	Norwegian	Algerian	Dutch
Methane CH_4	98.39	85.8	86.9	81.31
Ethane C_2H_6	0.44	8.49	9	2.85
Propane C_3H_8	0.16	2.3	2.6	0.37
Butane C_4H_{10}	0.07	0.7	1.2	0.14

3. Natural Gas Combustion

The calculation of the flue gas composition of all fossil fuels is performed using stoichiometric equations, which determine minimum amount of oxygen (O_{min}), the resulting minimum amount of air (L_{min}) and the amount of gases that do not participate in the combustion process (especially N_2).

3.1 Stoichiometric equations

The stoichiometric equations, subsequently compiled into a combustion table, allow us to calculate the amount of individual components of the flue gas according to the declared chemical composition of the fuel, assuming perfect fuel combustion (without CO), with a predefined excess air [1].

Table 3: Declared composition of the Transit NG

	Natural gas Transit		*Stoichiometric equations*
Methane	**CH_4**	**98.39 %**	$CH_4 + 2{\cdot}O_2 = CO_2 + 2{\cdot}H_2O$
Ethane	**C_2H_6**	**0.44 %**	$C_2H_6 + 3.5{\cdot}O_2 = 2{\cdot}CO_2 + 3{\cdot}H_2O$
Propane	**C_3H_8**	**0.16 %**	$C_3H_8 + 5{\cdot}O_2 = 3{\cdot}CO_2 + 4{\cdot}H2O$
Butane	**C_4H_{10}**	**0.07 %**	$C_4H_{10} + 6.5{\cdot}O_2 = 4{\cdot}CO_2 + 5{\cdot}H2O$
Nitrogen	**N_2**	**0.84 %**	$V\,N_2 = N_2 + O_{min}{\cdot}3.76{\cdot}n$

Table 4: Combustion table of the Transit NG

	Component	Quantity ($m^3 \cdot m^{-3}$)	O_{min}	Flue gas ($m^3 \cdot m^{-3}$)			
				CO_2	H_2O	N_2	O_2
Methane	CH_4	0.9839	1.968	0.984	1.968		
Nitrogen	N_2	0.0084				0.008	
Ethane	C_2H_6	0.0044	0.015	0.009	0.013		
Propane	C_3H_8	0.0016	0.008	0.005	0.006		
Butane	C_4H_{10}	0.0007	0.005	0.003	0.004		
Carbon dioxide	CO_2	0.0007		0.001			
Nitrogen airy	$N_{2,air}$					8.254	
Oxygen airy	$O_{2,air}$						0.200
	Subtotal	**1.00**	**1.996**	**1.001**	**1.991**	**8.263**	**0.200**
	Total						**11.454**

By perfect combustion of 1 m^3 of Transit NG under ideal pressure conditions and with an excess of air n = 1.1 (average setting of burners), we get 11.5 m^3 of flue gas, of which the monitored CO_2 component is 1 m^3.

In the following identical combustion table, we change the composition of NG to the declared composition of Norwegian gas and obtain the following values:

Table 5: Declared composition of the Norwegian NG

	Natural gas		***Stoichiometric equations***
	Norwegian		
Methane	CH_4	**85.80 %**	$CH_4 + 2 \cdot O_2 = CO2 + 2 \cdot H_2O$
Ethane	C_2H_6	**8.49 %**	$C_2H_6 + 3.5 \cdot O_2 = 2 \cdot CO_2 + 3 \cdot H_2O$
Propane	C_3H_8	**2.30 %**	$C_3H_8 + 5 \cdot O_2 = 3 \cdot CO_2 + 4 \cdot H_2O$
Butane	C_4H_{10}	**0.70 %**	$C_4H_{10} + 6.5 \cdot O_2 = 4 \cdot CO_2 + 5 \cdot H_2O$
Nitrogen	N_2	**0.96 %**	$V\ N_2 = N_2 + O_{min} \cdot 3.76 \cdot n$
Carbon dioxide	CO_2	**1.50 %**	$V\ O_2 = O_{min} \cdot (n\text{-}1)$

Table 6: Combustion table of the Norwegian NG

	Component	Quantity ($m^3 \cdot m^{-3}$)	Omin	Flue gas ($m^3 \cdot m^{-3}$)			
				CO_2	H_2O	N_2	O_2
Methane	CH_4	0.858	1.716	0.858	1.716		
Nitrogen	N_2	0.0096				0.010	
Ethane	C_2H_6	0.0849	0.297	0.170	0.255		
Propane	C_3H_8	0.023	0.115	0.069	0.092		
Butane	C_4H_{10}	0.007	0.046	0.028	0.035		
Carbon dioxide	CO_2	0.015		0.015			
Nitrogen airy	$N_{2,air}$					8.990	
Oxygen airy	$O_{2,air}$						0.217
	Subtotal	**0.998**	**2.174**	**1.140**	**2.098**	**9.000**	**0.217**
	Total						**12.455**

By perfect combustion of 1 m^3 of Norwegian NG under ideal pressure conditions and with an excess of air n = 1.1, we get 12.5 m^3 of flue gas, of which the monitored CO2 component is 1.14 m^3.

The graphically shown ratio of all generated flue gas components of both NG can be seen in the following Figure 1.

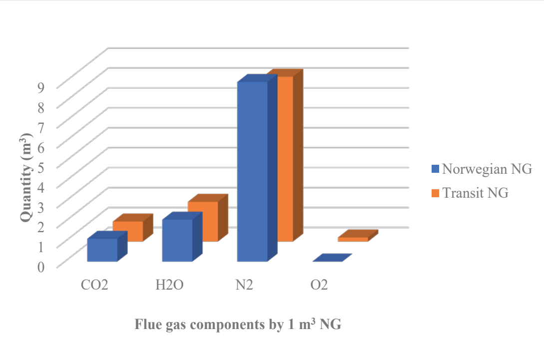

Figure 1: Graph of formed flue gas components of both NG

Based on the results of stoichiometric equations and a comparison of the amount of flue gas, the following partial conclusions can be drawn: Compared to Transit NG, the combustion of 1 m^3 of Norwegian NG increases the oxygen consumption by 8.9 %, the amount of CO_2 by 13.9 % and the amount of flue gas by 8.7 %.

3.2 Change in the higher and lower calorific value of natural gas

When calculating the higher and lower calorific values, we use an empirical formula [1]:

$$Q_s = 127.7 \cdot \phi_{H_2} + 398.5 \cdot \phi_{CH_4} + 704.2 \cdot \phi_{C_2H_6} + 1018.2 \cdot \phi_{C_3H_8} + 1340.2 \cdot \phi_{C_4H_{10}} \quad (kJ \cdot m^{-3}) \tag{1}$$

$$Q_i = 107.6 \cdot \phi_{H_2} + 358.0 \cdot \phi_{CH_4} + 643.5 \cdot \phi_{C_2H_6} + 935.7 \cdot \phi_{C_3H_8} + 1235.5 \cdot \phi_{C_4H_{10}} \quad (kJ \cdot m^{-3}) \tag{2}$$

where ϕ_i volume fraction of the i-th component NG (%).

Table 7: Change in lower heat value during the transition to Norwegian NG

Transit NG		
Higher calorific value Q_s	39 617	kJ·m^{-3}
Lower calorific value Q_i	35 733	kJ·m^{-3}
Norwegian NG		
Higher calorific value Q_s	43 181	kJ·m^{-3}
Lower calorific value Q_i	39 048	kJ·m^{-3}

Based on the calculation of the lower calorific value of the individual components, the following partial conclusion can be drawn: During the transition from Transit to Norwegian gas, the lower heat value of NG will increase by 9.0 %.

4. Conclusion

The increase in the amount of flue gas and lower heat value is a direct consequence of the increase in the amount of ethane in NG at the expense of methane. Norwegian gas has a 9.3 % higher calorific value than transit gas. Burning 1 m3 of Norwegian gas produces 8.7 % more flue gas. The same heat output of the furnace can thus be achieved with Norwegian gas with a 9.3 % lower gas volume flow. The amount of flue gas per unit of output will thus be somewhat lower than that of transit gas.

In the case of the transition to the Norwegian NG, it will be necessary to check the set combustion conditions of the burners (due to the risk of chemical non burning) and to make an approximate measurement of the flue gas composition, especially with regard to the possible formation of CO.

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