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DESIGN AND CALCULATION OF HEATING OF PYROLITIC FURNACE BASIC MODULE
OF THE PYROMATIC UNIT

NÁVRH A VÝPOČET OHŘÍVÁNÍ ZÁKLADNÍHO MODULU PYROLÝZNÍ PECE JEDNOTKY
PYROMATIC

Abstract

The article is focused on definition of optimum parameters of the pyrolitic unit basic module heating with respect to specified operating conditions. Suitable available fuel gases are propane and natural gas. The total capacity of torches is 200 kW. All energetic values has been calculated and reconciled for the both gases with respect to significant factors influencing the heating process course. In the conclusion the established values are summarized and evaluated.

Abstrakt

Příspěvek je zaměřen na určení optimálních parametrů ohřívání základního modulu pyrolýzní jednotky vzhledem k požadovaným podmínkám provozu. Jako vhodné topné plyny jsou k dispozici propan a zemní plyn. Celkový výkon hořáků činí 200 kW. Veškeré energetické veličiny jsou vypočteny a srovnány pro oba plyny, a to z podstatných hledisek ovlivňujících průběh spalovacího procesu. V závěru příspěvku je shrnutí a vyhodnocení zjištěných hodnot.

1 DESCRIPTION OF THE PYROMATIC UNIT AND THE BASIC MODULE FUNCTION

The Pyromatic Unit is the technological facility for processing of organic matters (within the processing range from 50 to 200 kg per hour) without oxidant inlet for the purpose of degrading of these matters and recycling of valuable energetic products without negative environmental impacts.

The facility operation comprises feeding of the input raw material to the reaction chamber, its heating without air and cleaning and cooling of produced pyrolytic gas. It also includes outlet of solid and liquid products. Pyromatic Unit is fully automated. In the course of operation all important parameters are monitored by many measuring elements connected to the control room, where all values are displayed and recorded.

In the basic module of the facility – in the retort – the material is disintegrated by heat and in the same time it is moved by two primary crew conveyors and one secondary screw conveyor (that feeds the material back to the retort inlet part). The retort of the total length 4000 mm is made of stainless austenitic steel 253 MA (EN 1.4835). The process temperature ranges from 600°C to 800°C. The time of the material stay in the retort ranges from 45 minutes to 60 minutes.

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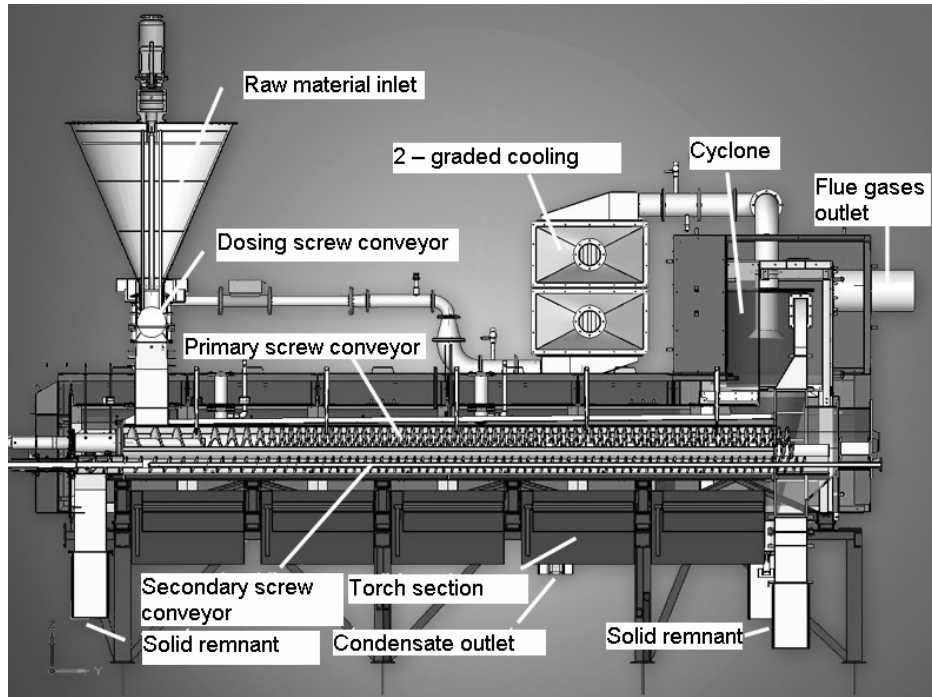
Fig. 1: Pyrolitic unit PYROMATIC

Pyrolitic gas generated in the retort goes to a cyclone where it is cleaned of solid impurities and it continues to an air cooler and a water cooler. In the course of gas cooling some hydrocarbons are condensed into liquid faction, the properties of which are determined mainly by the composition of material treated by pyrolisis. After this treatment the gas is either accumulated in the gas holder of directly consumed.
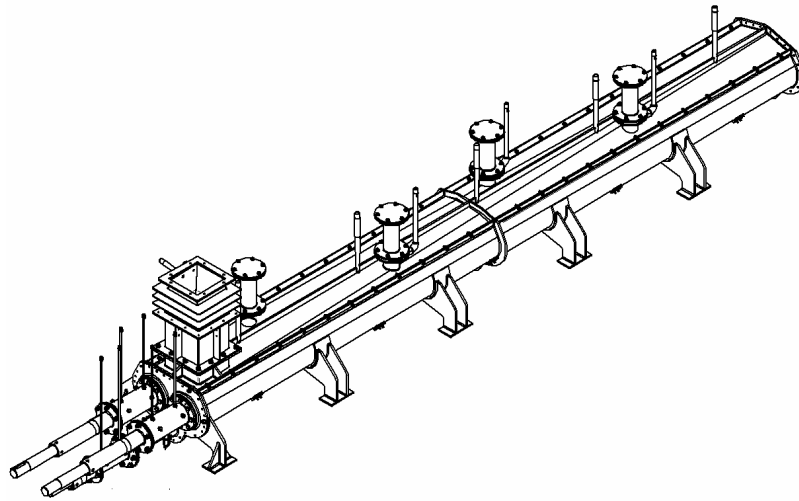
Fig. 2: Retort Set

2 RETORT HEATING METHOD AND FUEL GASES CHARACTERISTICS

Heat for the retort heating is delivered by indirect heating by five section of gas torches (S1 through S5) arranged one after another under the retort body. Heating gas is either propane or natural gas for higher throughput. Maximum required thermal input of the furnace is 200 kW that means maximum 40 kW for one section of torches. According to the pyrolisis temperature setting the temperature of flue gases ranges from 600°C to 800°C.

Burning air enters individual sections through the hole under the torches and it could be regulated either by throttling on the inlet or by revolutions of the flues gas fan.

Tab. 1: Fuel gases properties

	Propane	**Natural gas**
Calorific value [kJ.m$^{-3}_N$]	93 180	35 870
Combustion heat [kJ.m$^{-3}_N$]	101 205	39 794
Density [kg.m$^{-3}_N$]	2,01	0,73
Gas chemical composition [%]	C_3H_8 - 100	CH_4 - 98,39 C_MH_N - 0,7
		CO_2 - 0,07 N_2 - 0,84

3 CALCULATION METHOD AND DETERMINATION OF COMBUSTION PROCESS OPTIMUM CONDITIONS FOR PROPOSED FUEL GASES

Following summary presents formulas necessary for calculation of the fuel gas and combustion airs quantities, flow, flue gases composition and other parameters of the combustion process.

Based on the calorific values and required thermal capacity necessary gas flow $\dot{V}_{pl}$ is determined by the formula:

$$\dot{V}_{pl} = \frac{P}{Q_{i,pl}} \; \left[m_N^3 \cdot s^{-1} \right], \tag{1}$$

where:
P – thermal output of torches [kW],
$Q_{i,pl}$ – fuel gas calorific value [kJ.m$^{-3}_N$].

Minimum quantity of dry air $V_{vz,t}^s$ necessary for combustion of a fuel gas unit is calculated from the gas composition and oxygen content in the air:

$$V_{vz,t}^s = \frac{1}{0,21} \cdot \Sigma \left(x + \frac{y}{4} \right) \cdot C_x H_y + 3,8 \cdot C_M H_N + 0,5 \cdot CO + 0,5 \cdot H_2 - O_2 \; \; [m_N^{\;3} \cdot m_N^{\;-3}], \tag{2}$$

where:
$C_M H_N$ – content of ethylenic hydro carbons in the fuel gas [1],
$C_x H_y$ – content of saturated hydrocarbons in the fuel gas [1],
CO – content of carbon monoxide in the fuel gas [1],
H_2 – content of hydrogen in the fuel gas [1],
O_2 – content of oxygen in the fuel gas [1].

Value defining the actual quantity of humid air $V_{vz,s}^{v}$ considers air humidity and the surplus air with direct impact on the flue gases temperature:

$$V_{vz,s}^{v} = V_{vz,t}^{s} \cdot \upsilon \cdot n \ [m_N^{3} \cdot m_N^{-3}], \tag{3}$$

where:
n – air surplus [1],
υ – humidity coefficient [1] (set $\upsilon = 1,03$).

Produced dry flue gases $V_{sp,s}^{s}$ are calculated as a sum of produced carbon dioxide and surplus air:

$$V_{sp,s}^{s} = V_{CO_2} + V_{N_2} + (n-1) \cdot V_{vz,t}^{s} \ [m_N^{3} \cdot m_N^{-3}], \tag{4}$$

where the carbon dioxide content in the flue gases V_{CO_2} is determined by the formula:

$$V_{CO_2} = CO + CO_2 + \Sigma x \cdot C_X H_X + 2,6 \cdot C_M H_N \ [m_N^{3} \cdot m_N^{-3}] \tag{5}$$

and content of nitrogen V_{N_2} is determined by the formula:

$$V_{N_2} = N_2 + 0,79 \cdot V_{vz,t}^{s} \ [m_N^{3} \cdot m_N^{-3}] \tag{6}$$

Humidity of flue gases V_{H_2O} is determined by the formula:

$$V_{H_2O} = H_2 + \Sigma \frac{y}{2} \cdot C_x H_y + 2,4 \cdot C_M H_N + (v-1) \cdot V_{vz,t}^{s} \cdot n \ [m_N^{3} \cdot m_N^{-3}] \tag{7}$$

and actual content of humid flue gases $V_{sp,s}^{v}$ is determined consequently:

$$V_{sp,s}^{v} = V_{sp,s}^{s} + V_{H_2O} \ [m_N^{3} \cdot m_N^{-3}]. \tag{8}$$

Concentrations of individual factions in the flue gases are expressed as a volume share of respective element is proportion to the total volume of humid flue gases:

$$\omega_{CO_2} = \frac{V_{CO_2}}{V_{sp,s}^{v}} \cdot 100 \ [\%], \tag{9}$$

$$\omega_{N_2} = \frac{V_{N_2,pal} + 0,79 \cdot V_{vz,t}^{s} \cdot n}{V_{sp,s}^{v}} \cdot 100 \ [\%], \tag{10}$$

$$\omega_{O_2} = \frac{0,21 \cdot (n-1) \cdot V_{vz,t}^{s}}{V_{sp,s}^{v}} \cdot 100 \ [\%], \tag{11}$$

$$\omega_{H_2O} = \frac{V_{H_2O}}{V_{sp,s}^{v}} \cdot 100 \ [1]. \tag{12}$$

Calculated values allow us to establish flow volume of air $V_{vz,s}^{\dot{v}}$ and flow volume of produced flue gases $V_{sp,s}^{\dot{v}}$ with respect to the fuel gas flow:

$$V_{vz,s}^{\dot{v}} = V_{vz,s}^{v} \cdot \dot{V}_{pl} \quad [m_N^3 \cdot s^{-1}], \tag{13}$$

$$V_{sp,s}^{\dot{v}} = V_{sp,s}^{v} \cdot \dot{V}_{pl} \quad [m_N^3 \cdot s^{-1}]. \tag{14}$$

Based on the composition and enthalpy the temperature of flue gases t_{sp} can be determined using the formula:

$$t_{sp} = \frac{-a_{sp} \pm \sqrt{a_{sp}^2 - 4 \cdot b_{sp} \cdot (-i_{sp})}}{2 \cdot b_{sp}} \quad [^\circ C], \tag{15}$$

Flue gases enthalpy i_{sp} is determined from thermal capacity and flow volume of humid flue gases produced:

$$i_{sp} = \frac{P}{V_{sp,s}^{\dot{v}}} \quad \left[\frac{kJ}{m_N^3}\right]. \tag{16}$$

Values of auxiliary coefficients a_{sp} and b_{sp} are derived from formulas expressing dependence of the gas enthalpy on the temperature. General formula is as follows:

$$i_i = a_i \cdot t + b_i \cdot t^2, \tag{17}$$

for actual gases:

oxygen - $i_{O_2} = 1{,}32107 \cdot t + 0{,}000141614 \cdot t^2$,

nitrogen - $i_{N_2} = 1{,}28392 \cdot t + 0{,}000108509 \cdot t^2$,

carbon dioxide - $i_{CO_2} = 1{,}73614 \cdot t + 0{,}000413123 \cdot t^2$,

and water - $i_{H_2O} = 1{,}47301 \cdot t + 0{,}000250404 \cdot t^2$.

Auxiliary coefficient can be determined from contents of individual gases in the flues gases:

$$a_{sp} = \sum_{i=1}^{i=n} a_i \cdot \omega_i, \tag{18}$$

$$b_{sp} = \sum_{i=1}^{i=n} b_i \cdot \omega_i. \tag{19}$$

Dependences of relevant resulting values on the air surplus possibly on required thermal capacity of torches are presented in Figures **3**, **4** and **5**.

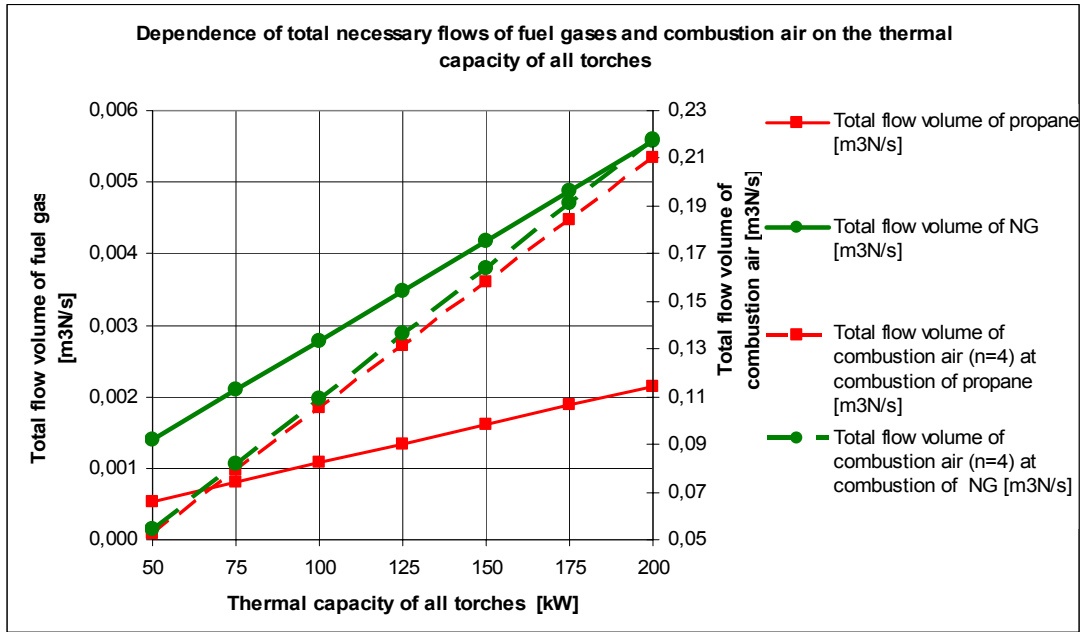*Note: All volume units apply for normal conditions.*

Fig. 3: Required flows of combustion air and heating gases with respect to the heating capacity of torches
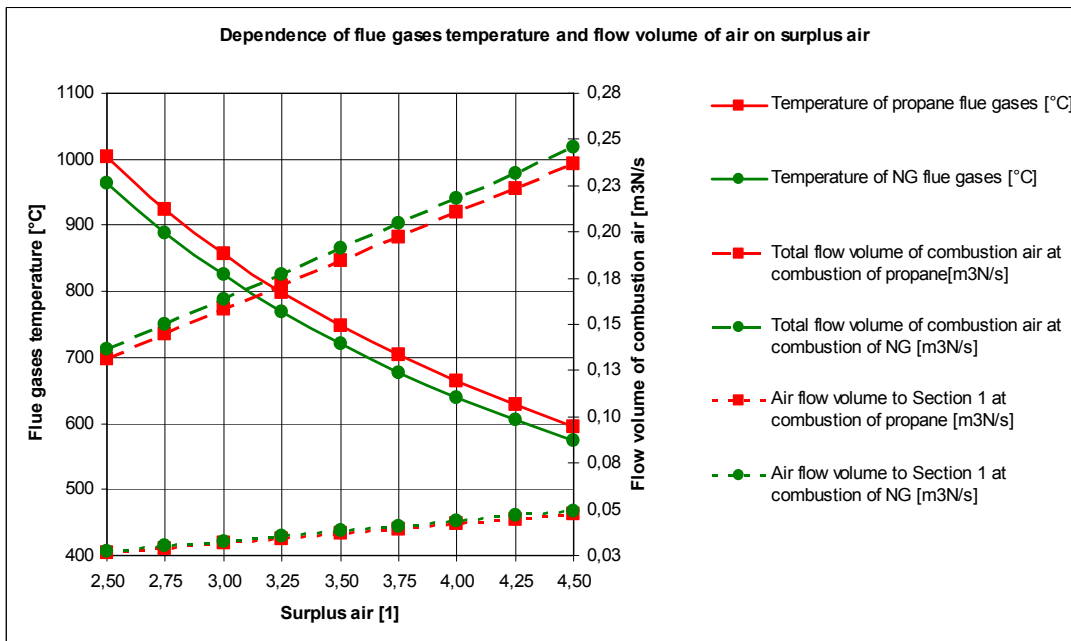

Fig. 4: Dependence of the flue gases temperature on flow volumes or air and surplus air
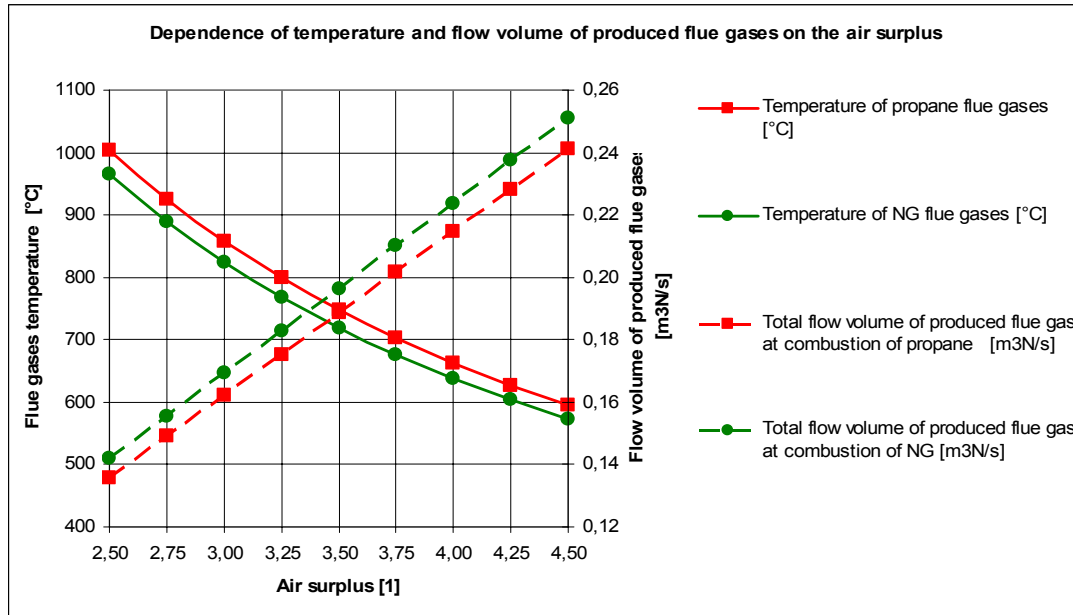
Fig. 5: Dependence of the temperature and the flow volume of produced flue gases of the surplus air

4 CONCLUSION AND SUMMARY OF RESULTING VALUES

The objective of presented calculation is to establish optimum conditions of the burning process in Pyromatic pyrolitic unit furnace for heating either with propane or natural gas.

The calculation established that maximum thermal capacity of torches 200 kW requires the supply of $2,15.10^{-3}$ $m^3_N.s^{-1}$ of propane or $5,58.10^{-3}$ $m^3_N.s^{-1}$ of natural gas. With respect to required flue gases temperature ranging from 600°C to 800°C it is necessary to supply combustion air with the surplus of approximately 3,25 to 5,50 for the both gases.

The combustion air flow volume for the surplus 4 and maximum capacity of torches is $0,2105$ $m^3_N.s^{-1}$ for propane and $0,2182$ $m^3_N.s^{-1}$ for natural gas.

Summary of all relevant energetic parameters is contained in the following tables.

Tab. 2: Necessary flows of combustion air and flue gases with respect to the thermal output of torches

Required thermal output of all torches [kW]		50	75	100	125	150	175	200
Total gas flow volume $[m^3_N.s^{-1}]$	Propane	0,00054	0,00080	0,00107	0,00134	0,00161	0,00188	0,00215
Total flow volume of combustion air $[m^3_N.s^{-1}]$		0,0526	0,0790	0,1053	0,1316	0,1579	0,1842	0,2105
Total gas flow volume $[m^3_N.s^{-1}]$	NG	0,00139	0,00209	0,00279	0,00348	0,00418	0,00488	0,00558
Total flow volume of combustion air $[m^3_N.s^{-1}]$		0,0545	0,0818	0,1091	0,1364	0,1636	0,1909	0,2182
Gas flow volume per one section $[m^3_N.s^{-1}]$	Propane	0,00011	0,00016	0,00021	0,00027	0,00032	0,00038	0,00043
Gas flow volume per one section $[l_N.min^{-1}]$		6,44	9,66	12,88	16,10	19,32	22,54	25,76
Air flow volume per one section $[m^3_N.s^{-1}]$		0,0105	0,0158	0,0211	0,0263	0,0316	0,0368	0,0421
Gas flow volume per one section $[m^3_N.s^{-1}]$	NG	0,00028	0,00042	0,00056	0,00070	0,00084	0,00098	0,00112
Gas flow volume per one section $[l_N.min^{-1}]$		16,73	25,09	33,45	41,82	50,18	58,54	66,91
Air flow volume per one section $[m^3_N.s^{-1}]$		0,0109	0,0164	0,0218	0,0273	0,0327	0,0382	0,0436

Note: Flow volume of combustion air apply for the surplus n = 4.

Tab. 3: Combustion process energetic parameters in dependence of the air surplus

Air surplus [1]		2,50	2,75	3,00	3,25	3,50	3,75	4,00	4,25	4,50
Theoretical quantity of dry air [$m^3_N.m^{-3}_N$]	Propane	23,81								
	NG	9,50								
Actual quantity of humid air [$m^3_N.m^{-3}_N$]	Propane	61,31	67,44	73,57	79,70	85,83	91,96	98,10	104,23	110,36
	NG	24,46	26,90	29,35	31,79	34,24	36,68	39,13	41,57	44,02
CO_2 content in flue gases [$m^3_N.m^{-3}_N$]	Propane	3,00								
	NG	1,00								
N_2 content in flue gases [$m^3_N.m^{-3}_N$]	Propane	18,81								
	NG	7,51								
Actual quantity of dry flue gases [$m^3_N.m^{-3}_N$]	Propane	57,52	63,48	69,43	75,38	81,33	87,29	93,24	99,19	105,14
	NG	22,76	25,13	27,51	29,88	32,26	34,63	37,01	39,38	41,75
Humidity in flue gases [$m^3_N.m^{-3}_N$]	Propane	5,79	5,96	6,14	6,32	6,50	6,68	6,86	7,04	7,21
	NG	2,70	2,77	2,84	2,91	2,98	3,05	3,12	3,20	3,27
Actual quantity of humid flue gases [$m^3_N.m^{-3}_N$]	Propane	63,31	69,44	75,57	81,70	87,83	93,96	100,10	106,23	112,36
	NG	25,46	27,90	30,35	32,79	35,24	37,68	40,13	42,58	45,02
CO_2 concentration in flue gases [%]	Propane	4,74	4,32	3,97	3,67	3,42	3,19	3,00	2,82	2,67
	NG	3,94	3,59	3,30	3,06	2,85	2,66	2,50	2,36	2,23
N_2 concentration in flue gases [%]	Propane	74,28	74,49	74,67	74,82	74,95	75,07	75,17	75,25	75,33
	NG	73,71	73,98	74,20	74,38	74,54	74,68	74,81	74,91	75,01
O_2 concentration in flue gases [%]	Propane	11,85	12,60	13,23	13,77	14,23	14,63	14,99	15,30	15,58
	NG	11,75	12,51	13,14	13,68	14,15	14,55	14,91	15,22	15,50
H_2O concentration in flue gases [%]	Propane	9,14	8,59	8,13	7,74	7,40	7,11	6,85	6,62	6,42
	NG	10,59	9,92	9,36	8,88	8,46	8,10	7,79	7,51	7,26
Flow volume of produced flue gases [$m^3_N.s^{-1}$] — S1 Propane		0,0272	0,0298	0,0324	0,0351	0,0377	0,0403	0,0430	0,0456	0,0482
S1-5 Propane		0,1359	0,1490	0,1622	0,1754	0,1885	0,2017	0,2148	0,2280	0,2412
S1 NG		0,0284	0,0311	0,0338	0,0366	0,0393	0,0420	0,0448	0,0475	0,0502
S1-5 NG		0,1419	0,1556	0,1692	0,1828	0,1965	0,2101	0,2238	0,2374	0,2510
Flow volume of necessary air [$m^3_N.s^{-1}$] — S1 Propane		0,0263	0,0290	0,0316	0,0342	0,0368	0,0395	0,0421	0,0447	0,0474
S1-5 Propane		0,1316	0,1448	0,1579	0,1711	0,1842	0,1974	0,2105	0,2237	0,2369
S1 NG		0,0273	0,0300	0,0327	0,0355	0,0382	0,0409	0,0436	0,0464	0,0491
S1-5 NG		0,1364	0,1500	0,1636	0,1773	0,1909	0,2045	0,2182	0,2318	0,2454
Flue gases enthalpy [$kJ.m^{-3}_N$]	Propane	1471,82	1341,87	1233,01	1140,48	1060,87	991,65	930,91	877,18	829,32
	NG	1409,07	1285,57	1181,97	1093,83	1017,92	951,86	893,85	842,51	796,75
Flue gases temperature [°C]	Propane	**1003**	**924**	**857**	**799**	**748**	**703**	**663**	**628**	**596**
	NG	**965**	**889**	**824**	**769**	**720**	**677**	**639**	**604**	**574**

Note: Flow volumes of air and flue gases are related to maximum thermal capacity of torches that means one section S1 with the output 40 [kW], all five section S1-5 with the output 200 [kW].

LITERATURE

[1] Blahož, V., Lapčík, V.: *Návody do cvičení z termomechaniky*, Technical University of Ostrava, 1989

[2] Noskievič, P.: *Spalování uhlí,* Technical University of Ostrava, 2005

[3] Obroučka, K.: *Termické odstraňování a energetické využívání odpadů*, Technical University of Ostrava, 2001

[4] Rédr, M.: *Základy tepelné techniky*, Technical University of Ostrava, 1988