



TOKOVI ENERGIJE I ENERGETSKA EFIKASNOST

GORIVA, SAGOREVANJE I UTICAJ NA ŽIVOTNU SREDINU

GORIVA, SAGOREVANJE I UTICAJ NA ŽIVOTNU SREDINU

- Zadatak 1.

Izračunati teorijske parametre sagorevanja prirodnog zemnog gasa koji se do naših domaćinstava distribuira od strane „Srbijagas“ i uporediti sa vrednostima datim od strane distributera.

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- Zadatak 2.

Izračunati emisiju CO₂ i SO₂ u gasovi nastalim sagorevanjem sledećih goriva: ugalj i mazut. Temperatura izlaznih gasova je $t_{FG} = 250^{\circ}\text{C}$, sadržaj kiseonika u produktima sagorevanja je $v_{O_2} = 7\%$, sadržaj ugljen-monoksida je $v_{CO} = 100 \text{ ppm}$, a pritisak je $p = 4 \text{ bar}$. Parametri vazduha potrebnog za sagorevanje goriva su: barometarski pritisak $p = 1 \text{ bar}$, temperatura $t_v = 25^{\circ}\text{C}$, relativna vlažnost $\varphi = 55 \%$.

Gorivo/Sastav	c	h	o	n	s	a	w	
Mrki ugalj	55,97	3,57	10,53	0,34	3,46	10,83	15,3	
Mazut	84,28	11,1	0,2	0,5	0,62	0,3	3	

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- Zadatak 2.

$$a) m_{CO_2} = v_{CO_2} \cdot 44 \cdot B \left[\frac{kg_{CO_2}}{kg_G} \right]$$

$$m_{SO_2} = v_{SO_2} \cdot 64 \cdot B \left[\frac{kg_{SO_2}}{kg_G} \right]$$

$$m_{CO_2} = 0,1251 \cdot 44 \cdot 0,3729 = 2,05 \left[\frac{kg_{CO_2}}{kg_G} \right]$$

$$m_{SO_2} = 0,0029 \cdot 64 \cdot 0,3729 = 0,07 \left[\frac{kg_{SO_2}}{kg_G} \right]$$

The screenshot shows a software interface for theoretical combustion calculations. The main window is titled "THEORETICAL COMBUSTION" and has two tabs: "FUEL COMPOSITION" and "FUEL PROPERTIES". A sub-window titled "FLUE GAS LOSS CALCULATION" is open, showing "MEASURED DATA" and "RESULTS OF CALCULATION".

MEASURED DATA

Flue Gas		Combustion Air (ta,db < 100 oC)	
Temperature, tFG [oC]	250,0	Pressure, Pa [bar]	1,000
Oxygen (by volume), O2 [%]	7,00	Temperature, ta,db [oC]	25,00
Carbon Monoxide (by volume), CO [ppm]	100	Relative Humidity, RH [%]	55,0
Pressure, PFG [bar]	4,000		

RESULTS OF CALCULATION

Flue gas		Combustion Air	
Air to Fuel ratio, A [-]	10,9128	Pressure, Pa [bar]	1,000
kmol of dry flue gas per kg of fuel, B [kmol/kgF]	0,3729	Dry Bulb Temperature, ta,db [oC]	25,00
CO2 (vol.), vCO2 [%]	12,51	Relative Humidity, RH [%]	55,0
SO2 (vol.), vSO2 [%]	0,29	Wet Bulb Temperature, tawb [oC]	18,60
N2 (vol.), vN2 [%]	80,19	Absolute Humidity, xa [-]	0,01102
Molar mass of dry flue gas, MDFG [kg/kmol]	30,38	Enthalpy, ha [kJ/kg]	53,18
Specific heat of flue gas, cpFG [kJ/kgK]	1,0099	Density, roa [kg/m3]	1,161
Absolute humidity of flue gas, xFG [-]	0,05	Vapor pressure, pv [bar]	0,01741
Enthalpy of flue gas, hFG [kJ/kg]	408,68		
Loss of Heat Energy, QFG [kJ/kgF]	4049,67		
Flue gas loss, q2 [%]	17,77		
Density of flue gas, roFG [kg/m3]	2,70		
Excess Air, lam [-]	1,4888		
Incomplete combustion loss, q3 [%]	0,05		
Carbon Dioxide Emission, mCO2 [kgCO2/kgF]	1,37		
Sulfur Dioxide Emission, mSO2 [kgSO2/kgF]	0,05		
Water Emission (total), mH2O [kgH2O/kgF]	0,59		

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- Zadatak 2.

$$b) m_{CO_2} = v_{CO_2} \cdot 44 \cdot B \left[\frac{kg_{CO_2}}{kg_G} \right]$$

$$m_{SO_2} = v_{SO_2} \cdot 64 \cdot B \left[\frac{kg_{SO_2}}{kg_G} \right]$$

$$m_{CO_2} = 0,1065 \cdot 44 \cdot 0,6596 = 3,09 \left[\frac{kg_{CO_2}}{kg_G} \right]$$

$$m_{SO_2} = 0,0003 \cdot 64 \cdot 0,6596 = 0,01 \left[\frac{kg_{SO_2}}{kg_G} \right]$$

FUEL GAS LOSS CALCULATION

MEASURED DATA

Flue Gas		Combustion Air (ta,db < 100 oC)	
Temperature, tFG [oC]	250,0	Pressure, Pa [bar]	1,000
Oxygen (by volume), O2 [%]	7,00	Temperature, ta,db [oC]	25,00
Carbon Monoxide (by volume), CO [ppm]	100	Relative Humidity, RH [%]	55,0
Pressure, PFG [bar]	4,000		

RESULTS OF CALCULATION

Flue gas		Combustion Air	
Air to Fuel ratio, A [-]	19,8162	Pressure, Pa [bar]	1,000
kmol of dry flue gas per kg of fuel, B [kmol/kgF]	0,6596	Dry Bulb Temperature, ta,db [oC]	25,00
CO2 (vol.), vCO2 [%]	10,65	Relative Humidity, RH [%]	55,0
SO2 (vol.), vSO2 [%]	0,03	Wet Bulb Temperature, tawb [oC]	18,60
N2 (vol.), vN2 [%]	82,31	Absolute Humidity, xa [-]	0,01102
Molar mass of dry flue gas, MDFG [kg/kmol]	29,99	Enthalpy, ha [kJ/kg]	53,18
Specific heat of flue gas, cpFG [kJ/kgK]	1,0144	Density, roa [kg/m3]	1,161
Absolute humidity of flue gas, xFG [-]	0,06	Vapor pressure, pv [bar]	0,01741
Enthalpy of flue gas, hFG [kJ/kg]	441,30		
Loss of Heat Energy, QFG [kJ/kgF]	7675,97		
Flue gas loss, q2 [%]	17,41		
Density of flue gas, roFG [kg/m3]	2,65		
Excess Air, lam [-]	1,4711		
Incomplete combustion loss, q3 [%]	0,04		
Carbon Dioxide Emission, mCO2 [kgCO2/kgF]	2,06		
Sulfur Dioxide Emission, mSO2 [kgSO2/kgF]	0,01		
Water Emission (total), mH2O [kgH2O/kgF]	1,25		

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- Zadatak 2.

Gorivo/Emisija	m_{CO_2} (kg _{CO2} /kg _G)	m_{SO_2} (kgSO ₂ /kgG)
Mrki ugalj	2,05	0,07
Mazut	3,09	0,01

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- Zadatak 3.

Izračunati procentualni gubitak energije sa produktima sagorevanja za goriva i uslove iz prethodna 2 zadatka.

- Gubitak toplotne energije vlažnih produkata sagorevanja je:

$$Q_{PS} = m_{PS} \cdot h_{PS} - m_V \cdot h_V$$

- Procentualni gubitak energije sa produktima sagorevanja (GPS):

$$GPS = \frac{Q_{PS}}{H_g} \cdot 100$$

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- Zadatak 3.

a) Na osnovu sastava goriva korišćenjem softvera dobijaju se sledeći podaci:

$$H_g = 22,79 \text{ MJ/kg} = 22790 \text{ kJ/kg}$$

$$Q_{PS} = 4049,67 \text{ kJ/kg}_G$$

$$GPS = \frac{Q_{PS}}{H_g} \cdot 100 = \frac{4049,67}{22790} \cdot 100 = 17,77 \%$$

THEORETICAL COMBUSTION

FUEL COMPOSITION

- Carbon, c [%] = 55,97
- Hydrogen, h [%] = 3,57
- Sulfur, s [%] = 3,46
- Nitrogen, n [%] = 0,34
- Oxygen, o [%] = 10,53
- Moisture, w [%] = 15,30
- Ash, a [%] = 10,83

FUEL PROPERTIES

- GCV(15oC) [MJ/kg] = 22,79
- NCV(15oC) [MJ/kg] = 21,61

THEORETICAL COMBUSTION

- Theoretical Air and Fule Ratio, At [kgA/kgF] = 7,33
- Theoretical Flue Gas and Fuel Ratio, Bt [kmolFG/kgF] = 0,2486
- Maximum Content of Carbon Dioxide, CO2 [%] = 18,76
- Theoretical Flue Gas and Fuel Ratio, Bt' [kgFG/kgF] = 6,97
- Carbon Dioxide Emission, mCO2 [kgCO2/kgF] = 2,05
- Sufur Dioxide Emission, mSO2 [kgSO2/kgF] = 0,07
- Water Emission (only from fuel), mH2O [kgH2O/kgF] = 0,47

FLUE GAS LOSS CALCULATION

MEASURED DATA

Flue Gas		Combustion Air (ta,db < 100 oC)	
Temperature, tFG [oC]	250,0	Pressure, Pa [bar]	1,000
Oxygen (by volume), O2 [%]	7,00	Temperature, ta,db [oC]	25,00
Carbon Monoxide (by volume), CO [ppm]	100	Relative Humidity, RH [%]	55,0
Pressure, PFG [bar]	4,000		

RESULTS OF CALCULATION

Flue gas		Combustion Air	
Air to Fuel ratio, A [-]	10,9128	Pressure, Pa [bar]	1,000
kmol of dry flue gas per kg of fuel, B [kmol/kgF]	0,3729	Dry Bulb Temperature, ta,db [oC]	25,00
CO2 (vol.), vCO2 [%]	12,51	Relative Humidity, RH [%]	55,0
SO2 (vol.), vSO2 [%]	0,29	Wet Bulb Temperature, tawb [oC]	18,60
N2 (vol.), vN2 [%]	80,19	Absolute Humidity, xa [-]	0,01102
Molar mass of dry flue gas, MDFG [kg/kmol]	30,38	Enthalpy, ha [kJ/kg]	53,18
Specific heat of flue gas, cpFG [kJ/kgK]	1,0099	Density, roa [kg/m3]	1,161
Absolute humidity of flue gas, xFG [-]	0,05	Vapor pressure, pv [bar]	0,01741
Entahply of flue gas, hFG [kJ/kg]	408,68		
Loss of Heat Energy, QFG [kJ/kgF]	4049,67		
Flue gas loss, q2 [%]	17,77		
Density of flue gas, roFG [kg/m3]	2,70		
Excess Air, lam [-]	1,4888		
Incomplete combustion loss, q3 [%]	0,05		
Carbon Dioxide Emission, mCO2 [kgCO2/kgF]	1,37		
Sufur Dioxide Emission, mSO2 [kgSO2/kgF]	0,05		
Water Emission (total), mH2O [kgH2O/kgF]	0,59		

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- Zadatak 3.

b) Na osnovu sastava goriva korišćenjem softvera dobijaju se sledeći podaci:

$$H_g = 44,09 \text{ MJ/kg} = 44090 \text{ kJ/kg}$$

$$Q_{PS} = 7675,97 \text{ kJ/kg}_G$$

$$GPS = \frac{Q_{PS}}{H_g} \cdot 100 = \frac{7675,97}{44090} \cdot 100 = 17,41 \%$$

THEORETICAL COMBUSTION

FUEL COMPOSITION

- Carbon, c [%] = 84,28
- Hydrogen, h [%] = 11,10
- Sulfur, s [%] = 0,62
- Nitrogen, n [%] = 0,50
- Oxygen, o [%] = 0,20
- Moisture, w [%] = 3,00
- Ash, a [%] = 0,30

FUEL PROPERTIES

- GCV(15oC) [MJ/kg] = 44,09
- NCV(15oC) [MJ/kg] = 41,52

Buttons: Flue Gas Loss, Export to Excel, Close

THEORETICAL COMBUSTION

- Theoretical Air and Fule Ratio, At [kg/kgF] = 13,47
- Theoretical Flue Gas and Fuel Ratio, Bt [kmolFG/kgF] = 0,4397
- Maximum Content of Carbon Dioxide, CO2 [%] = 15,97
- Theoretical Flue Gas and Fuel Ratio, Bt' [kgFG/kgF] = 12,32
- Carbon Dioxide Emission, mCO2 [kgCO2/kgF] = 3,09
- Sufur Dioxide Emission, mSO2 [kgSO2/kgF] = 0,01
- Water Emission (only from fuel), mH2O [kgH2O/kgF] = 1,03

FLUE GAS LOSS CALCULATION

MEASURED DATA

Flue Gas		Combustion Air (ta,db < 100 oC)	
Temperature, tFG [oC]	250,0	Pressure, Pa [bar]	1,000
Oxygen (by volume), O2 [%]	7,00	Temperature, ta,db [oC]	25,00
Carbon Monoxide (by volume), CO [ppm]	100	Relative Humidity, RH [%]	55,0
Pressure, PFG [bar]	4,000		

Buttons: Calculate, Export to Excel, Diagram, Close

RESULTS OF CALCULATION

Flue gas		Combustion Air	
Air to Fuel ratio, A [-]	19,8162	Pressure, Pa [bar]	1,000
kmol of dry flue gas per kg of fuel, B [kmol/kgF]	0,6596	Dry Bulb Temperature, ta,db [oC]	25,00
CO2 (vol.), vCO2 [%]	10,65	Relative Humidity, RH [%]	55,0
SO2 (vol.), vSO2 [%]	0,03	Wet Bulb Temperature, tawb [oC]	18,60
N2 (vol.), vN2 [%]	82,31	Absolute Humidity, xa [-]	0,01102
Molar mass of dry flue gas, MDFG [kg/kmol]	29,99	Enthalpy, ha [kJ/kg]	53,18
Specific heat of flue gas, cpFG [kJ/kgK]	1,0144	Density, roa [kg/m3]	1,161
Absolute humidity of flue gas, xFG [-]	0,06	Vapor pressure, pv [bar]	0,01741
Enthalpy of flue gas, hFG [kJ/kg]	441,30		
Loss of Heat Energy, QFG [kJ/kgF]	7675,97		
Flue gas loss, q2 [%]	17,41		
Density of flue gas, roFG [kg/m3]	2,65		
Excess Air, lam [-]	1,4711		
Incomplete combustion loss, q3 [%]	0,04		
Carbon Dioxide Emission, mCO2 [kgCO2/kgF]	2,06		
Sufur Dioxide Emission, mSO2 [kgSO2/kgF]	0,01		
Water Emission (total), mH2O [kgH2O/kgF]	1,25		

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- Zadatak 4.

Preduzeće planira prelazak sa lošijeg goriva na kvalitetnije. Potrebno je proveriti da je ovakav prelazak isplativ ako se zna da su godišnje uštede usled smanjenja emisija CO₂ po toni 20e ali je novo predloženo gorivo skuplje za 100%. Pokazati da li je ovakav potez preduzeća opravdan. Trenutna godišnja potrošnja goriva je 72t a cena goriva je 30e/t. Zanemaruju se investicioni troškovi. Za proračun koristiti donju toplotnu moć goriva.

Gorivo/Sastav	c	h	o	n	s	a	w	
Lignit	59,00	3,57	8,40	1,20	1,70	8,00	18,00	
Kameni ugalj	84,28	11,1	0,2	0,5	0,62	0,3	3	

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- Zadatak 4.

$$Q_1 = H_d \cdot M_G = 22450 \cdot 72000 = 1616400000 \text{ kJ} = 161,6 \text{ GJ}_{\text{god}}$$

$$m_{\text{CO}_2} = 2,16 \left[\frac{\text{kg}_{\text{CO}_2}}{\text{kg}_G} \right]$$

$$M_{\text{CO}_2} = 2,16 \left[\frac{\text{kg}_{\text{CO}_2}}{\text{kg}_G} \right] \cdot 72000 \text{ kg}_G = 155520 \text{ kg}_{\text{CO}_2}$$

THEORETICAL COMBUSTION

FUEL COMPOSITION

- Carbon, c [%] = 59,00
- Hydrogen, h [%] = 3,70
- Sulfur, s [%] = 1,70
- Nitrogen, n [%] = 1,20
- Oxygen, o [%] = 8,40
- Moisture, w [%] = 18,00
- Ash, a [%] = 8,00

FUEL PROPERTIES

- GCV(15oC) [MJ/kg] = 24,13
- NCV(15oC) [MJ/kg] = 22,85

THEORETICAL COMBUSTION

- Theoretical Air and Fule Ratio, At [kga/kgF] = 7,74
- Theoretical Flue Gas and Fuel Ratio, Bt [kmolFG/kgF] = 0,2620
- Maximum Content of Carbon Dioxide, CO2 [%] = 18,76
- Theoretical Flue Gas and Fuel Ratio, Bt' [kgFG/kgF] = 7,34
- Carbon Dioxide Emission, mCO2 [kgCO2/kgF] = 2,16
- Sufur Dioxide Emission, mSO2 [kgSO2/kgF] = 0,03
- Water Emission (only from fuel), mH2O [kgH2O/kgF] = 0,51

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- Zadatak 4.

$$Q_1 = Q_2 = H_d \cdot M_G = 41520 \cdot x = 1616400000 \text{ kJ}$$

$$x = \frac{1616400000}{41520} = 38900 \text{ kg}$$

$$m_{\text{CO}_2} = 3,09 \left[\frac{\text{kg}_{\text{CO}_2}}{\text{kg}_G} \right]$$

$$M_{\text{CO}_2} = 3,09 \left[\frac{\text{kg}_{\text{CO}_2}}{\text{kg}_G} \right] \cdot 38900 \text{ kg}_G = 120201 \text{ kg}_{\text{CO}_2}$$

$$N = (155,5 - 120,2) \cdot 20 \frac{\text{euro}}{t} = 35,3 \cdot 20 = 706 \text{ eura}$$

The screenshot displays a software window titled "THEORETICAL COMBUSTION" with a blue header bar. The interface is divided into several sections:

- FUEL COMPOSITION:** A list of fuel components with their respective percentages in input fields:
 - Carbon, c [%] = 84,28
 - Hydrogen, h [%] = 11,10
 - Sulfur, s [%] = 0,62
 - Nitrogen, n [%] = 0,50
 - Oxygen, o [%] = 0,20
 - Moisture, w [%] = 3,00
 - Ash, a [%] = 0,30
- FUEL PROPERTIES:** Two energy values are shown in light blue boxes:
 - GCV(15oC) [MJ/kg] = 44,09
 - NCV(15oC) [MJ/kg] = 41,52
- Buttons:** Three buttons are located at the bottom right: "Flue Gas Loss" (with a dotted border), "Export to Excel", and "Close".
- THEORETICAL COMBUSTION:** A section at the bottom containing combustion parameters in light blue boxes:
 - Theoretical Air and Fuel Ratio, At [kga/kgF] = 13,47
 - Theoretical Flue Gas and Fuel Ratio, Bt [kmolFG/kgF] = 0,4397
 - Maximum Content of Carbon Dioxide, CO2 [%] = 15,97
 - Theoretical Flue Gas and Fuel Ratio, Bt' [kgFG/kgF] = 12,32
 - Carbon Dioxide Emission, mCO2 [kgCO2/kgF] = 3,09
 - Sulfur Dioxide Emission, mSO2 [kgSO2/kgF] = 0,01
 - Water Emission (only from fuel), mH2O [kgH2O/kgF] = 1,03

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- Zadatak 4.

$$G_{1, god} = 72 t \cdot 30 \text{ €/t} = 2160 \text{ €}$$

$$G_{2, god} = 38,9 t \cdot 60 \text{ €/t} = 2334 \text{ €}$$

Ukupna godišnja ušteda je:

$$N - \Delta G = 706 \text{ €} - (2334 \text{ €} - 2160 \text{ €}) = 532 \text{ €}$$

The screenshot displays a software window titled 'THEORETICAL COMBUSTION'. It is divided into several sections:

- FUEL COMPOSITION:** Lists the percentage of various elements in the fuel:
 - Carbon, c [%] = 84,28
 - Hydrogen, h [%] = 11,10
 - Sulfur, s [%] = 0,62
 - Nitrogen, n [%] = 0,50
 - Oxygen, o [%] = 0,20
 - Moisture, w [%] = 3,00
 - Ash, a [%] = 0,30
- FUEL PROPERTIES:** Shows the heating values:
 - GCV(15oC) [MJ/kg] = 44,09
 - NCV(15oC) [MJ/kg] = 41,52
- Buttons:** 'Flue Gas Loss', 'Export to Excel', and 'Close'.
- THEORETICAL COMBUSTION:** Shows the results of the combustion calculation:
 - Theoretical Air and Fuel Ratio, At [kga/kgF] = 13,47
 - Theoretical Flue Gas and Fuel Ratio, Bt [kmolFG/kgF] = 0,4397
 - Maximum Content of Carbon Dioxide, CO2 [%] = 15,97
 - Theoretical Flue Gas and Fuel Ratio, Bt' [kgFG/kgF] = 12,32
 - Carbon Dioxide Emission, mCO2 [kgCO2/kgF] = 3,09
 - Sulfur Dioxide Emission, mSO2 [kgSO2/kgF] = 0,01
 - Water Emission (only from fuel), mH2O [kgH2O/kgF] = 1,03