International Journal of Environmental Science and Green Technology
https://journals.ayu.edu.kz

Modeling of the Oxidation of Lignite and Calculation of Carbon Footprint in the Gas Phase

Timur Maimekov[1], Damira Sambaeva[2], Zarlyk Maimekov[3]*, Nurbek Zheenbaev[4], Kubat Kemelov[5], Mirlan Moldobaev[6]

[1] *Research Assistant, Institute of Physics named after Academician Zh. Zheenbaev, National Academy of Sciences of the Kyrgyz Republic, 720071 Bishkek.*
[2] *Prof. Dr., Kyrgyz State Technical University named after. I. Razzakov, 720044 Bishkek.*
[3] *Prof. Dr., Kyrgyz-Turkish "Manas" University, 720038 Bishkek.*
[4] *Prof. Dr., Institute of Physics named after Academician Zh. Zheenbaev, National Academy of Sciences of the Kyrgyz Republic, 720071 Bishkek.*
[5] *Assistant professor, Dr., Kyrgyz-Turkish "Manas" University, 720038 Bishkek.*
[6] *Dr., Kyrgyz-Turkish "Manas" University, 720038 Bishkek.*

*Corresponding Author e-mail: zarlyk.maymekov@manas.edu.kg

Keywords

coal-air system

oxidation

carbon footprint

thermodynamic modeling

entropy

gas phase

Abstract

The paper examines local coal sources and presents their physicochemical characteristics. The Kara-Keche coal deposit has been adopted as the model system, with the following composition percentages: hydrogen (H) - 3.65%, carbon (C) - 79.03%, nitrogen (N) - 0.84%, sulfur (S) - 0.55%, and moisture content considering oxygen (H_2O) - 18.47%. Thermodynamic modeling of the coal oxidation process at the maximum entropy of the system was carried out. The concentration distribution of components containing H, C, N, S, and O, as well as active particles and condensed phases, was established over a wide temperature range (298-3000 K). At the theoretical combustion temperature of coal (1998 K), the complete composition of carbon-containing substances in the gas phase was determined, and the additive value of the carbon footprint was calculated for the first time, taking into account the initial mass of carbon in the solid phase. The anthropogenic carbon load in the gas phase is useful for assessing the carbon capacity per unit of industrial production obtained from the combustion of solid fuel.

Cite

Maimekov, T., Sambaeva, D., Maimekov, Z., Zheenbaev, N., Kemelov, K., Moldobaev, M. (2025.) Modeling of the Oxidation of Lignite and Calculation of Carbon Footprint in the Gas Phase. International Journal of Environmental Science and Green Technology, 1(2), 14-24. doi: 10.5281/zenodo.15744640

Article Process

Submission Date: 10.03.2025; Revision Date: 24.03.2025; Accepted Date: 16.04.2025; Published Date: 25.06.2025;

INTRODUCTION

It is well-known that in the Kyrgyz Republic, the primary sources of energy and heat are solid fuels, namely local coals from various deposits. Consequently, the coal-fuel industry encompasses a full range of technological processes for the processing, utilization, and combustion of solid fuels. There are approximately 70 coal deposits with reserves of 2.2 billion tons, each with different characteristics (Dzhamanbaev, 1983; Solpuev, 1996; Sabyrbekov, 2019). The main coal deposits are located in four basins (Kashirin, 1951; 1990): Southern Fergana (Suluktu, Kyzyl-Kiya, Beshburhan, Abshir, Almalyk), Ozgon (Kok-Jangak, Kumbel, Zyndan); Northern Fergana (Tash-Komur, Kara-Tut, Tegenek); Kavak (Kok-Moynok, Mingkush, Kara-Keche), as well as in three coal-bearing areas (Solpuev, 1996): Alay, Alabuka-Chatyrkol, and Southern Isyk-Gol (see Fig. 1).

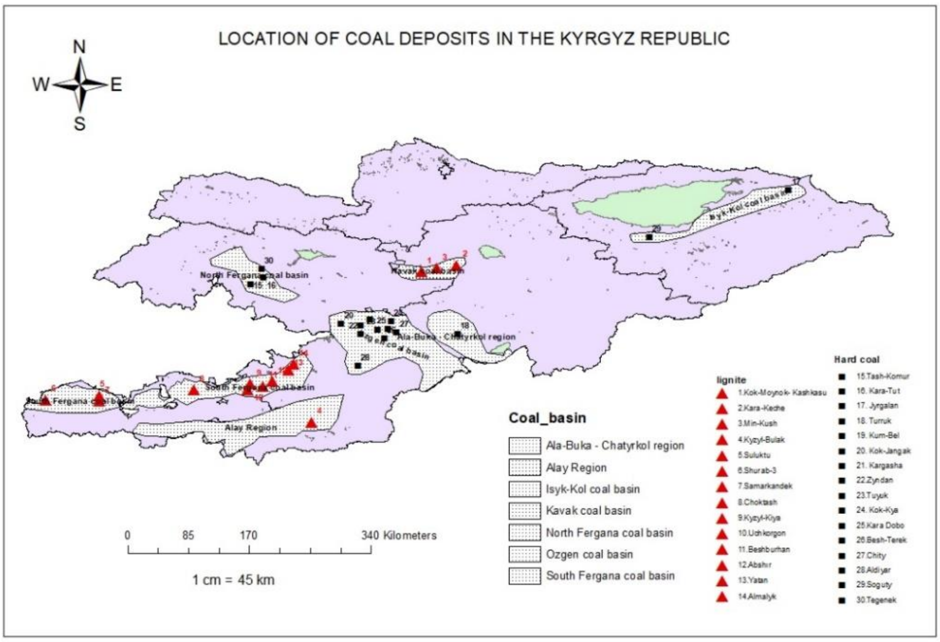

Fig.1. *Location of coal deposits in the Kyrgyz Republic*

Each year, approximately 2 million tons of coal are used during the heating season. The energy sector obtains 70% of its energy and heat from the Kara-Keche coal deposit (Sabyrbekov, 2019). Considering these circumstances, the physicochemical characteristics of the Kara-Keche coal deposit are provided in table 1 (Kashirin, 1951; Dzhamanbaev, 1983), and based on these, a thermodynamic model for this study has been developed.

MATERIALS AND METHODS

In the computational experiments, the coals of the Kara-Keche deposit were considered as the model system with the following composition percentages: hydrogen (H) - 3.65%, carbon (C) - 79.03%, nitrogen (N) - 0.84%, sulfur (S) - 0.55%, total moisture (H_2O) - 18.47%, and oxygen (O) - 15.88% (Table 1) (Mironov, 1991; Cheng, 2008; Tazhibaev, 2016; Kapakov, 2022). The oxidation processes of the solid phase were studied over a wide temperature range (298-3000 K) at the maximum entropy of the system using the "Terra" software complex (Sinyarev, 1982; Belov, 2013). The excess oxidizer (air) was set at 1.5 (alpha factor): N - 10.05; O - 2.67. The calorific value of the coal was 29.57 MJ/kg. The overall calculation matrix, considering all elements in the phases, was as follows (mol/kg): H – 49.209, C – 57.087, N – 6.745, S – 0.149, O – 10.343.

Table 1. Physico-chemical and thermo-technical characteristics of the Kara-Keche coal deposit

Technical composition					
Sample	humidity (W), %		Ash content, A^d, %	volatile substances (V),%	bitumen (B), %
	external	analytical			
1K	9,68	11,68	10,24	34,45	0,45
2K	6,07	16,05	16,85	38,45	0,64
Physicochemical characteristics					
Sample	humic acids (HA), %	density, g/cm³		functional composition, %	
		approx.	actual	-COOH	-OH

1K	6,3	1,17	1,51	0,99	5,27
2K	10,29	1,21	1,58	0,78	4,61

Sample	**Specific heat capacity**			
	Q_i		Q_s	
	kcal/kg	MJ/kg	kcal/kg	MJ/kg
1K	5095	21,32	7514	31,44
2K	4911	20,55	7730	32,34

Sample	**Elemental composition, %**					**Atomic bond**	
	C	H	N	S	O	C/H	O/C
1K	77,59	4,1	1,32	0,46	16,53	1,58	0,16
2K	76,13	4,61	1,17	0,47	17,62	1,38	0,17
анализ	79,03	3,65	0,84	0,55	15,88		

Sample	**Petrographic composition, %**				
	vitrinite V_t	semivitrinite S_v	inertinite Y	liptinite + macerinite L+M	Min.sub.ces, M_1
1K	35	7	44,5	5	8,5

continuation of the table

The chemical composition of ash								
Sample	Macronutrients in ash, %							
	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O+K_2O	MnO	TiO_2
1K	22	12	25	17	3	0,3	0,4	0,12
2K	25	5	29	13	4	0,12	0,5	0,7

Sample	**The yield of semi-coke products, %**			
	Semi-coke, T_s	Tar, s	pyrogenic water, W_s	Gas, G_s
1K	74,36	2,85	1,32	10,5
2K	73,79	3,07	2	8,1

Sample	**Gas composition of coal pyrolysis process, %**					
	CO_2+H_2S	C_nH_m	CO	H_2	$C_nH_{2n}+_2$	N_2
1K	40	2,7	14	10,7	29,6	3
2K	40,2	2,7	13,5	11	29,9	2,7

Sample	**Composition of the tar group, %**							
	$C_{св.}$	Carboxylic acids	Phenols	primary resins	asphaltenes	paraffins.	neutral oils	Sol.dis. in CH_3OH
1K	6,2	1,1	20	1,2	3	1	50	10,5
2K	6,9	1	20	1,2	3	1	49,9	10,6

The physical properties of brown coal have been thoroughly studied and are summarized in the accompanying table 1 and fig. 2-5 (Solomon, 1992; Karabaev, 2015; Speight, 2015; Avgushevich, 2019; Niksa, 2019; Azhgaliyeva, 2021; Wilberforce, 2021; Murko, 2022; Maimekov, 2023; Ritchie, 2024).

RESULTS AND DISCUSSIONS

It was noted that the main coal deposits in the republic are located in four basins (Solpuev, 1996), of which the Kavak Valley includes sections: Kara-Keche, Donguz, Min-Kush, Kok-Moynok, Ak-Ulak, Tuura-Kavak, Kashka-Suu, Sary-Kamysh, etc. The total geological reserves of lignite in the republic are estimated at 2.5 billion tons, of which the Kara-Keche basin (Naryn region, Zhumgal district) accounts for 437.8 million tons, and the Min-Kush - 116 million tons (Kashirin, 1951; Dzhamanbaev, 1983). The basin is 75 km long, in the western part bordered by the Kokomeren River, in the eastern part by the Lake Son-Kol, in the southern part and northern part by the foothills of Moldotoo and Kavak-Too. Coals in the Kavak basin are classified as B (brown), 3B (third brown), and 3VF (third brown fusainite). According to their quality characteristics, gas, briquettes, coal-water fuel suspensions, liquid synthetic fuel, organic acids, and activated carbon can be obtained from the coals of Kara-Keche, Min-Kush, and Kashka-Suu (Kashirin, 1951; 1990).

Figures 2–5 show comparative values of the average moisture content, ash content, volatile matter yield and specific heat of combustion of coals in the republic, including coals from the Kara-Keche deposit (designation: light brown) (Dzhamanbaev, 1983; Solpuev, 1996; Sabyrbekov, 2019).

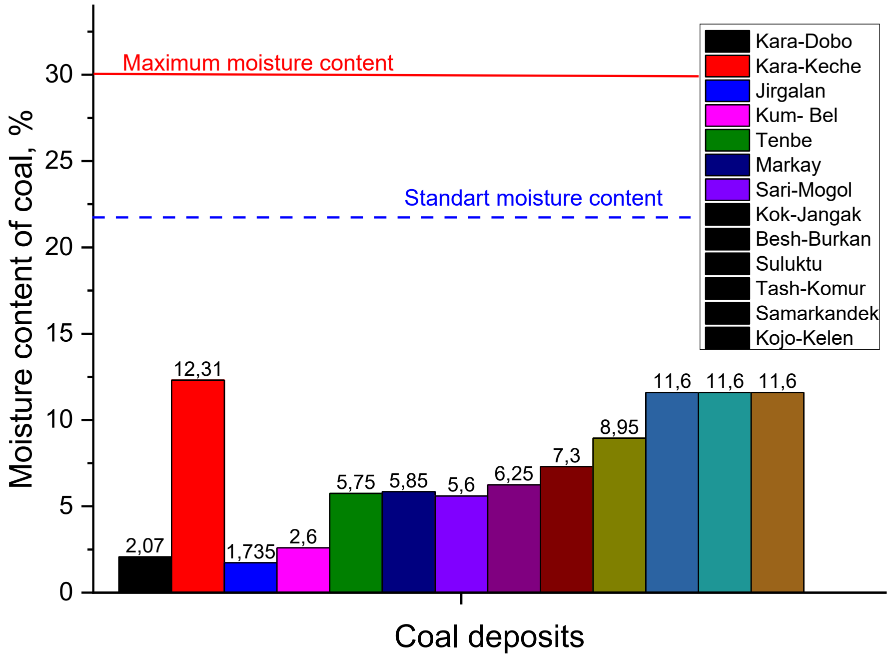

Fig. 2. *Average moisture content of coals from various deposits*

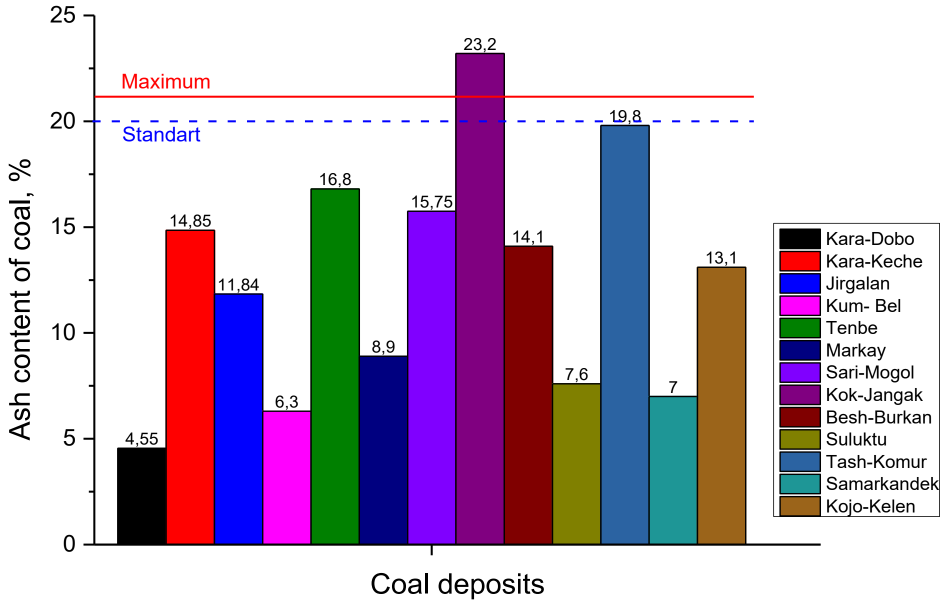

Fig. 3. *Ash content of coals from various deposits*

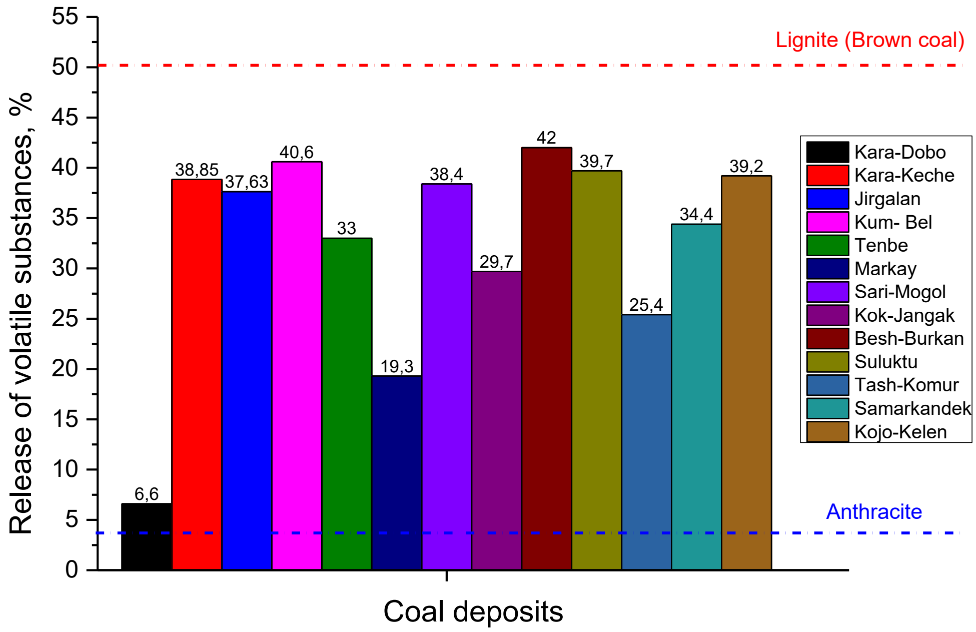

Fig. 4. Volatile matter yield from coals from various deposits

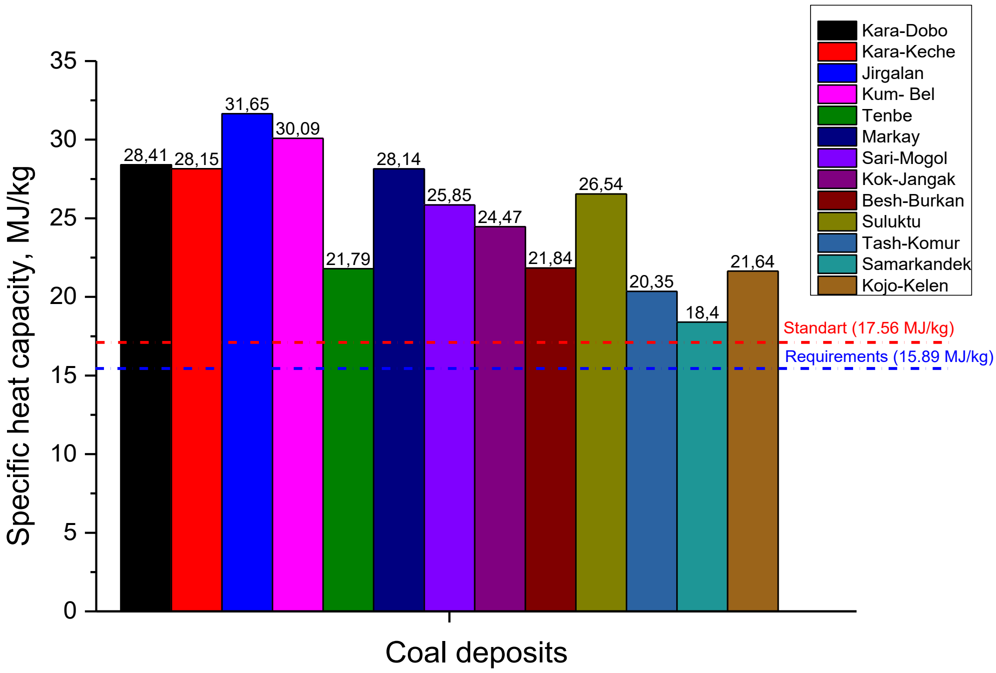

Fig.5. *Average specific heat capacity of combustion of coals for various deposits*

The above data show that the average specific heat of combustion of Kara-Keche coals is 28.14 MJ/kg, therefore its demand in winter conditions is significant in the fuel and energy complexes of the republic. Taking into account these circumstances, the Kara-Keche coal deposit was examined and thermodynamic modeling of the coal-air system was carried out. The concentration distribution of H, C, N, S, O containing components, active particles and condensed phases in the gas phase (mol/kg) was established at 1998 K, P = 0.1 MPa (Table 2).

Table 2. Concentration distribution of H, C, N, S, O-containing components, active particles, and condensed phases formed during the oxidation of Kara-Keche coal in air (mol/kg). T=1998 K; P=0.1 MPa; U=2095.1 kJ/kg; S=10.38 kJ/(kg K); I=2637.5 kJ/kg; Lt=0.40 Bt/(m K); Cp=2.50 kJ/(kg K).

$O=0.22\times10^{-9}$	$H=0.04$	$H_2=24.36$	$OH=0.15\times10^{-}$
$H_2O=0.7\times10^{-3}$	$S=0.73\times10^{-3}$	$S_2=0.001$	$S_3=0.47\times10^{-7}$
$SO=0.14\times10^{-6}$	$SO_2=0.84\times10^{-11}$	$S_2O=0.20\times10^{-9}$	$SH=0.01$
$H_2S=0.09$	$HSO=0.19\times10^{-10}$	$SOH=0.27\times10^{-9}$	$H_2SO=0.29\times10^{-11}$
$N=0.98\times10^{-8}$	$N_2=3.29$	$NO=0.19\times10^{-8}$	$NH=0.13\times10^{-6}$
$NH_2=0.79\times10^{-6}$	$NH_3=0.11\times10^{-3}$	$N_2H_2=0.60\times10^{-11}$	$NS=0.16\times10^{-5}$
$C(c)=46.49$	$C=0.11\times10^{-8}$	$C_2=0.81\times10^{-10}$	$C_3=0.10\times10^{-8}$
$CO=10.34$	$CO_2=0.72\times10^{-4}$	$C_2O=0.20\times10^{-7}$	$C_3O_2=0.66\times10^{-9}$
$CH=0.48\times10^{-8}$	$CH_2=0.69\times10^{-6}$	$CH_3=0.27\times10^{-3}$	$CH_4=0.006$
$C_2H=0.26\times10^{-5}$	$C_2H_2=0.019$	$C_2H_3=0.85\times10^{-5}$	$C_2H_4=0.81\times10^{-4}$
$C_2H_5=0.15\times10^{-7}$	$C_2H_6=0.26\times10^{-7}$	$C_3H=0.21\times10^{-4}$	$C_3H_4=0.13\times10^{-8}$
$C_3H_6=0.10\times10^{-10}$	$C_4H=0.70\times10^{-9}$	$C_4H_2=0.10\times10^{-3}$	$C_4H_4=0.27\times10^{-11}$
$C_5H_6=0.27\times10^{-11}$	$C_6H_6=0.10\times10^{-10}$	$CHO=0.47\times10^{-5}$	$CHO_2=0.25\times10^{-10}$
$CH_2O=0.27\times10^{-5}$	$CH_2O_2=0.8\times10^{-10}$	$CH_3O=0.15\times10^{-11}$	$CS=0.026$

CS_2=0.005	COS=0.001	CN=0.61 $\times10^{-5}$	CN_2=0.10 $\times10^{-7}$
C_2N=0.12 $\times10^{-7}$	C_2N_2=0.58 $\times10^{-5}$	NCO=0.83 $\times10^{-10}$	HCN=0.15
HNC=0.11 $\times10^{-4}$	C_2HN=0.43 $\times10^{-7}$	C_3HN=0.001	C_5HN=0.81 $\times10^{-3}$
C_7HN=0.18 $\times10^{-3}$	C_9HN=0.33 $\times10^{-4}$	N_2C=0.32 $\times10^{-5}$	-
SH^-=0.14 $\times10^{-11}$	NH^{4+}=0.91 $\times10^{-11}$	CHO^+=0.30 $\times10^{-11}$	CN^-=0.78 $\times10^{-11}$

Based on Table 2, the concentration distribution of carbon-containing components, active particles, and condensed phases in the gas phase was established (Fig. 6, Table 3).

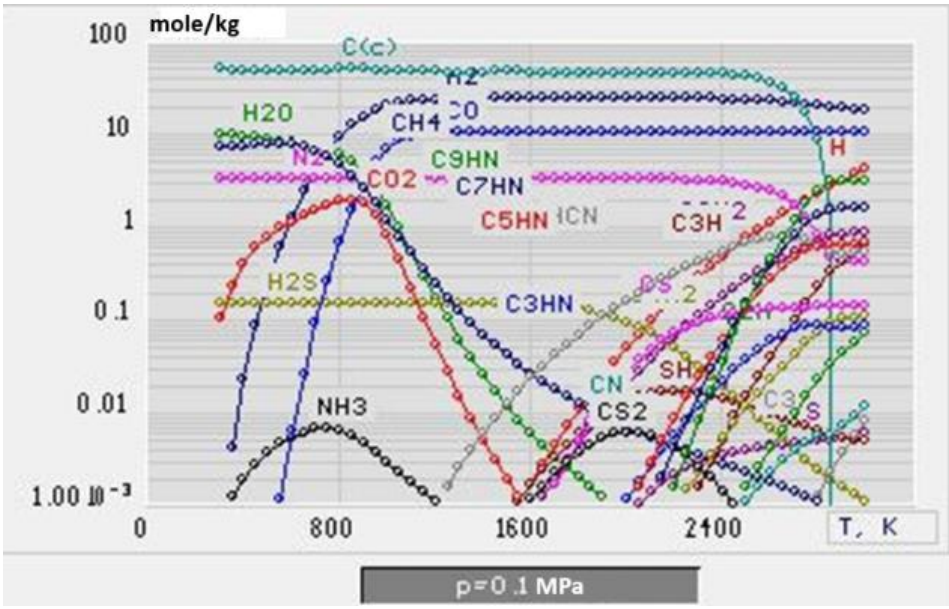

Fig. 6. *Concentration distribution of H, C, N, S, O - containing components, active particles, and condensed phases in the gas phase (mol/kg). T = 298 - 3000 K, P = 0.1 MPa.*

Table 3. Concentration distribution of carbon-containing components, active particles, and condensed phases in the gas phase (mol/kg). T = 1998 K, P = 0.1 MPa.

C(c)	C	C_2	C_3	C_4	C_5
46,49	1,1$\times10^{-9}$	8,1$\times10^{-11}$	1,0 $\times10^{-9}$	5,1$\times10^{-14}$	1,9 $\times10^{-13}$
CO	CO_2	C_2O	C_3O_2	CH	CH_2
10,34	7,2 $\times10^{-5}$	2,0 $\times10^{-8}$	6,6$\times10^{-10}$	4,8 $\times10^{-9}$	6,9 $\times10^{-7}$
CH_3	CH_4	C_2H	C_2H_2	C_2H_3	C_2H_4
2,0 $\times10^{-4}$	6,0 $\times10^{-3}$	2,7 $\times10^{-6}$	1,9 $\times10^{-2}$	8,5 $\times10^{-6}$	8,1 $\times10^{-5}$
C_2H_5	C_2H_6	C_3H	C_3H_4	C_3H_6	C_3H_8
1,5 $\times10^{-8}$	2,6 $\times10^{-8}$	2,1 $\times10^{-5}$	1,3 $\times10^{-9}$	1,0$\times10^{-11}$	2,4 $\times10^{-13}$
C_4H	C_4H_2	C_4H_4	C_4H_6	C_5H_6	C_6H_6
7 $\times10^{-10}$	1 $\times10^{-4}$	2,7$\times10^{-12}$	2 $\times10^{-13}$	2,7$\times10^{-12}$	1,0 $\times10^{-11}$
CHO	CHO_2	CH_2O	CH_2O_2	CH_3O	$C_2H_4O_2$
4,7 $\times10^{-6}$	2,5 $\times10^{-11}$	2,7 $\times10^{-6}$	8 $\times10^{-11}$	1,5$\times10^{-12}$	1,8 $\times10^{-15}$
C_3H_6O	C_2H_4O	CS	CS_2	COS	CN
4,6 $\times10^{-15}$	2,7 $\times10^{-14}$	2 $\times10^{-2}$	5 $\times10^{-3}$	1 $\times10^{-3}$	6,1 $\times10^{-6}$
CN_2	C_2N	C_2N_2	NCO	HCN	HNC
1,0 $\times10^{-8}$	1, $\times10^{-8}$	5,8 $\times10^{-6}$	8,3$\times10^{-11}$	1,5 $\times10^{-1}$	1 $\times10^{-5}$
C_2HN	C_3HN	C_5HN	C_7HN	C_9HN	N_2C

4,4 ×10^{-8}	1 ×10^{-3}	8 ×10^{-4}	1 ×10^{-4}	3,3 ×10^{-5}	3,2 ×10^{-6}
C^{2-}	CO^+	CH^+	C^+	C^{2+}	
1,9 ×10^{-17}	1,3 ×10^{-19}	2,6×10^{-21}	1,9×10^{-22}	1,93 ×10^{-22}	
CHO^+	CN^-	-	-	-	
3 ×10^{-12}	7,8 ×10^{-12}	-	-	-	

It has been noted that when calculating the carbon footprint, it is necessary to consider not only the masses of carbon oxides (CO, CO_2), methane, and condensed carbon C(s) (Magacho et al., 2024), but also all carbon-containing components, active particles, and condensed phases in the gas phase (Table 4) (Durojaye, 2020).

Table 4. Oxidation of Kara-Keche coal and calculation of additive carbon footprint in the gas phase (g/kg)

components and particles in the gas phase	content, mol/kg	content, grams	carbon in the gas phase, g/kg
C(c)	4,65 ×10^{1}	557,98	557,98
C	1,12 ×10^{-9}	1,34 ×10^{-8}	1,34 ×10^{-8}
C_2	8,19 ×10^{-11}	1,97 ×10^{-9}	1,97 ×10^{-9}
C_3	1,01 ×10^{-9}	3,64 ×10^{-8}	3,64 ×10^{-8}
C_4	5,12 ×10^{-14}	2,46 ×10^{-12}	2,46 ×10^{-12}
C_5	1,96 ×10^{-13}	1,18 ×10^{-11}	1,18 ×10^{-11}
CO	1,03 ×10^{1}	289,52	1,24 ×10^{2}
CO_2	7,22 ×10^{-5}	3,18 ×10^{-3}	8,66 ×10^{-4}
C_2O	2,05 ×10^{-8}	8,20 ×10^{-7}	4,92 ×10^{-7}
C_3O_2	6,63 ×10^{-10}	4,51 ×10^{-8}	1,62 ×10^{-6}
CH	4,83 ×10^{-9}	6,28 ×10^{-8}	5,80 ×10^{-8}
CH_2	6,92 ×10^{-7}	9,69 ×10^{-6}	8,30 ×10^{-6}
CH_3	2,73 ×10^{-4}	4,10 ×10^{-3}	3,28 ×10^{-3}
CH_4	6,78 ×10^{-3}	1,08 ×10^{-1}	8,13 ×10^{-2}
C_2H	2,70 ×10^{-6}	6,75 ×10^{-5}	6,48 ×10^{-5}
C_2H_2	1,96 ×10^{-2}	5,09 ×10^{-1}	4,70 ×10^{-1}
C_2H_3	8,52 ×10^{-6}	2,30 ×10^{-4}	2,04 ×10^{-4}
C_2H_4	8,18 ×10^{-5}	2,29 ×10^{-3}	1,96 ×10^{-3}
C_2H_5	1,58 ×10^{-8}	4,52 ×10^{-7}	3,79 ×10^{-7}
C_2H_6	2,66 ×10^{-8}	7,98 ×10^{-7}	6,38 ×10^{-7}
C_3H	2,16 ×10^{-5}	7,99 ×10^{-4}	7,78 ×10^{-4}
C_3H_4	1,37 ×10^{-9}	5,48 ×10^{-8}	4,93 ×10^{-8}
C_3H_6	1,05 ×10^{-11}	4,41 ×10^{-10}	3,78 ×10^{-10}
C_3H_8	2,48 ×10^{-13}	1,09 ×10^{-11}	8,93 ×10^{-12}
C_4H	7,00 ×10^{-10}	3,43 ×10^{-8}	3,36 ×10^{-8}
C_4H_2	1,01 ×10^{-4}	5,05 ×10^{-3}	4,48 ×10^{-3}
C_4H_4	2,73 ×10^{-12}	1,50 ×10^{-11}	1,31 ×10^{-10}
C_4H_6	2,06 ×10^{-13}	1,11 ×10^{-11}	9,89 ×10^{-12}
C_5H_6	2,76 ×10^{-12}	1,82 ×10^{-10}	1,6 ×10^{-10}

components and particles in the gas phase	content, mol/kg	content, grams	carbon in the gas phase, g/kg
C_6H_6	$1{,}09 \times 10^{-11}$	$8{,}50 \times 10^{-10}$	$7{,}85 \times 10^{-10}$
CS	$2{,}64 \times 10^{-2}$	$1{,}16 \times 10^{0}$	$3{,}17 \times 10^{-1}$
CS_2	$5{,}98 \times 10^{-3}$	$4{,}55 \times 10^{-1}$	$7{,}18 \times 10^{-2}$
COS	$1{,}67 \times 10^{-3}$	$1{,}00 \times 10^{-1}$	$2{,}01 \times 10^{-2}$
CN	$6{,}12 \times 10^{-6}$	$1{,}61 \times 10^{-4}$	$7{,}42 \times 10^{-5}$
CN_2	$1{,}03 \times 10^{-8}$	$4{,}12 \times 10^{-7}$	$1{,}24 \times 10^{-7}$
C_2N	$1{,}27 \times 10^{-8}$	$4{,}83 \times 10^{-7}$	$3{,}05 \times 10^{-7}$
C_2N_2	$5{,}86 \times 10^{-6}$	$3{,}05 \times 10^{-4}$	$1{,}41 \times 10^{-4}$
NCO	$8{,}39 \times 10^{-11}$	$3{,}52 \times 10^{-9}$	$1{,}01 \times 10^{-9}$
HCN	$1{,}5 \times 10^{-1}$	$4{,}26 \times 10^{0}$	$1{,}89 \times 10^{0}$
HNC	$1{,}20 \times 10^{-4}$	$3{,}24 \times 10^{-3}$	$1{,}44 \times 10^{-3}$
C_2HN	$4{,}40 \times 10^{-8}$	$1{,}72 \times 10^{-6}$	$1{,}06 \times 10^{-6}$
C_3HN	$1{,}11 \times 10^{-3}$	$5{,}65 \times 10^{-2}$	$3{,}99 \times 10^{-2}$
C_5HN	$8{,}17 \times 10^{-4}$	$6{,}13 \times 10^{-2}$	$4{,}90 \times 10^{-2}$
C_7HN	$1{,}81 \times 10^{-4}$	$1{,}79 \times 10^{-2}$	$1{,}52 \times 10^{-2}$
C_9HN	$3{,}32 \times 10^{-5}$	$4{,}08 \times 10^{-3}$	$3{,}59 \times 10^{-3}$
N_2C	$3{,}2 \times 10^{-6}$	$1{,}32 \times 10^{-4}$	$3{,}95 \times 10^{-5}$
C^+	$1{,}93 \times 10^{-22}$	$2{,}32 \times 10^{-21}$	$2{,}32 \times 10^{-21}$
C^{2+}	$1{,}93 \times 10^{-22}$	$4{,}63 \times 10^{-21}$	$4{,}63 \times 10^{-21}$
C^{2-}	$1{,}95 \times 10^{-17}$	$4{,}68 \times 10^{-16}$	$4{,}68 \times 10^{-16}$
CO^+	$1{,}38 \times 10^{-19}$	$3{,}86 \times 10^{-18}$	$1{,}66 \times 10^{-18}$
CH^+	$2{,}63 \times 10^{-21}$	$3{,}42 \times 10^{-20}$	$3{,}16 \times 10^{-20}$
CHO^+	$3{,}00 \times 10^{-12}$	$8{,}70 \times 10^{-11}$	$3{,}60 \times 10^{-11}$
CN^-	$7{,}85 \times 10^{-12}$	$2{,}04 \times 10^{-10}$	$9{,}42 \times 10^{-11}$

According to Table 4, the total mass of carbon in the gas phase was 685.04 g C, of which condensed carbon - 557.98 g, carbon monoxide - 124 g, acetylene - 0.47 g, hydrocyanic acid - 1.89 g, and the remaining carbon-containing particles account for approximately 0.7 % carbon. At the same time, the carbon content in the original coal was 67.98 mol/kg, i.e. 815.76 g C. Hence, the additive carbon footprint at the theoretical temperature of coal combustion (T = 1998 K) is 685.04/81.76 = 0.84, which is useful in assessing the carbon capacity per unit of product produced by burning coal from the Kara-Keche deposit.

From the data obtained, it is clear that 130.72 g or 16 % of carbon is lost due to the exergy of the flow, i.e. due to the dissipation of particles inside and outside the system when it interacts with the environment. It should be noted here that during the oxidation of coal in an oxidizing agent (T = 1998 K), the additive carbon footprint in the gas phase is mainly due to CO and $C_{(c)}$. However, when calculating the carbon footprint, it is necessary to take into account not only the mass of carbon oxides (CO, CO_2), acetylene, methane, and condensed carbon $C_{(c)}$, and all carbon-containing additive components, active particles, and condensed phases in the gas phase.

CONCLUSION

A model system of coal-air was considered with the overall calculation matrix (mol/kg): H – 49.209, C – 57.087, N – 6.745, S – 0.149, O – 10.343, and thermodynamic modeling of the oxidation process of the solid phase was conducted at the maximum entropy of the system. Concentration distributions of H, C, N, S, O-containing components, active particles, and condensed phases were determined over a wide temperature range (298-3000 K). At the theoretical combustion temperature of coal (1998 K), the complete composition of carbon-containing substances in the gas phase was identified, and for the first time, the additive value of the carbon footprint was calculated, taking into account the initial mass of carbon in the solid phase. The anthropogenic carbon load in the gas phase is valuable for assessing the carbon capacity per unit of industrial production obtained from the combustion of solid fuel**.**

REFERENCES

Avgushevich, I.V., Bronovets, T.M., Golovin, G.S., Sidoryuk, E.I., & Shulyakovskaya, L.V. (2019). Standard Test Methods for Coal. Classification of Coals. Moscow: 576

Azhgaliyeva, D., Mishra, R., Karymshakov, K., Kerimray, A., & Kapsalyamova, Z. (2021). What determines coal consumption for residential heating in Kazakhstan and the Kyrgyz Republic. Australasian Journal of Environmental Management, 28(4), 410-432.

Belov, G.V., & Trusov, B.G., (2013). Thermodynamic modeling of chemically reacting systems. M.: MSTU named after N.E. Bauman, 96

Böhringer, C., Fischer, C., Rosendahl, K.E., & Rutherford, T. F. (2022). Potential impacts and challenges of border carbon adjustments. Nature Climate Change, 12(1), 22-29.

Cheng, J., Zhou, J., Li, Y., Liu, J., & Cen, K. (2008). Improvement of coal water slurry property through coal physicochemical modifications by microwave irradiation and thermal heat. Energy & Fuels, 22(4), 2422-2428.

Dzhamanbaev, A.S. (1983). Coals of Kyrgyzstan and ways of their rational use. Ilim, Frunze: 234.

Durojaye, O., Laseinde, T., & Oluwafemi, I. (2020). A descriptive review of carbon footprint. Proceeding of 2nd International Conference on Human Systems Engineering and Design (IHSED2019). Munich.: Springer Int. Publishing, 2020. p. 960

Karabaev, S., Kharchenko, A., Lokshina, I., Gainullina, I., Dzhunushalieva, A., Lugovskoy, S., & Pendin, A. (2015). Physical and chemical characterization of raw and mechanochemically treated Humine and Humic acid from brown coals. Trans Tech Publications Ltd., 364, 18-26.

Kashirin, F.T., & Kashirina, Z.E. (1951). Geological description of the Kavak coal-bearing area and calculation of thermal coal reserves based on it. Funds Management. geol. Kirg. SSR: 83.

Kashirin, F.T. (1990). Kavak coal basin. Ilim, Frunze: 53-90

Kapakov, B. (2022). Problems and Prospects for Investments in the Coal Industry of the Kyrgyz Republic. Bulletin of Science and Practice. 8(12), 413-420

Maimekov, T.Z., Sambaeva, D.A., Moldobaev, M.B., Bazhirov, T.S., & Maimekov, Z.K. (2023). Forecasting and evaluation possibilities carbon footprint during combustion of fuel oil in medium and low power boilers. TFCE – Moscow, 57(5) 898-907.

Magacho, G., Espagne, E., & Godin, A. (2024). Impacts of the CBAM on EU trade partners: consequences for developing countries. Climate Policy, 24(2), 243-259.

Mironov, K.V. (1991). Handbook of a coal mining geologist. 2nd ed., Nedra, Moscow: 363

Murko, V. I., Dzhundubayev, A. K., Sultanaliyev, M. S., Kulagin,V. A., & Baranova M.P. (2022). Development of Technology of Receiving Water Coal Fuel from Brown Coals of a Field a Kara-Keche of the Kyrgyz Republic. Journal of Siberian Federal University. Engineering & Technologies, 15(6), 648-657.

Niksa, S. (2019). Process Chemistry of Coal Utilization: Impacts of coal quality and operating conditions. Woodhead Publishing.

Ritchie, H., & Roser M. (2024). CO_2 emissions dataset: Our sources and methods. Our World in Data.

Sabyrbekov, R., & Ukueva, N. (2019). Transitions from dirty to clean energy in low-income countries: insights from Kyrgyzstan. Central Asian Survey, 38(2), 255-274.

Sinyarev, G.B., Vatolin, N.A., Trusov, B.G., & Moiseev, G.K. (1982). Application of computers for thermodynamic calculations of metallurgical processes. M.: Nauka,– 264.

Solomon, P.R., Serio, M.A., & Suuberg, E.M. (1992). Coal pyrolysis: experiments, kinetic rates and mechanisms. Progress in energy and combustion science, 18(2), 133-220.

Solpuev, T. S., (1996). Coal deposits of the Kyrgyz Republic. Directory. Nasi Publ. Bishkek: 551.

Speight, J.G. (2015). Handbook of coal analysis. John Wiley & Sons, 34.

Tazhibaev, K.T., & Tazhibaev, D.K. (2016). Complex mastering of brown coal deposit KaraKeche. Bulletin of Kyrgyz Russian Slavic University. 16 (1) 183-186.

Wilberforce, T., Olabi, A.G., Sayed, E.T., Elsaid, K., & Abdelkareem, M.A. (2021). Progress in carbon capture technologies. Science of The Total Environment, 761, 143203.