PLASMA PROCESSING OF FOSSIL FUELS

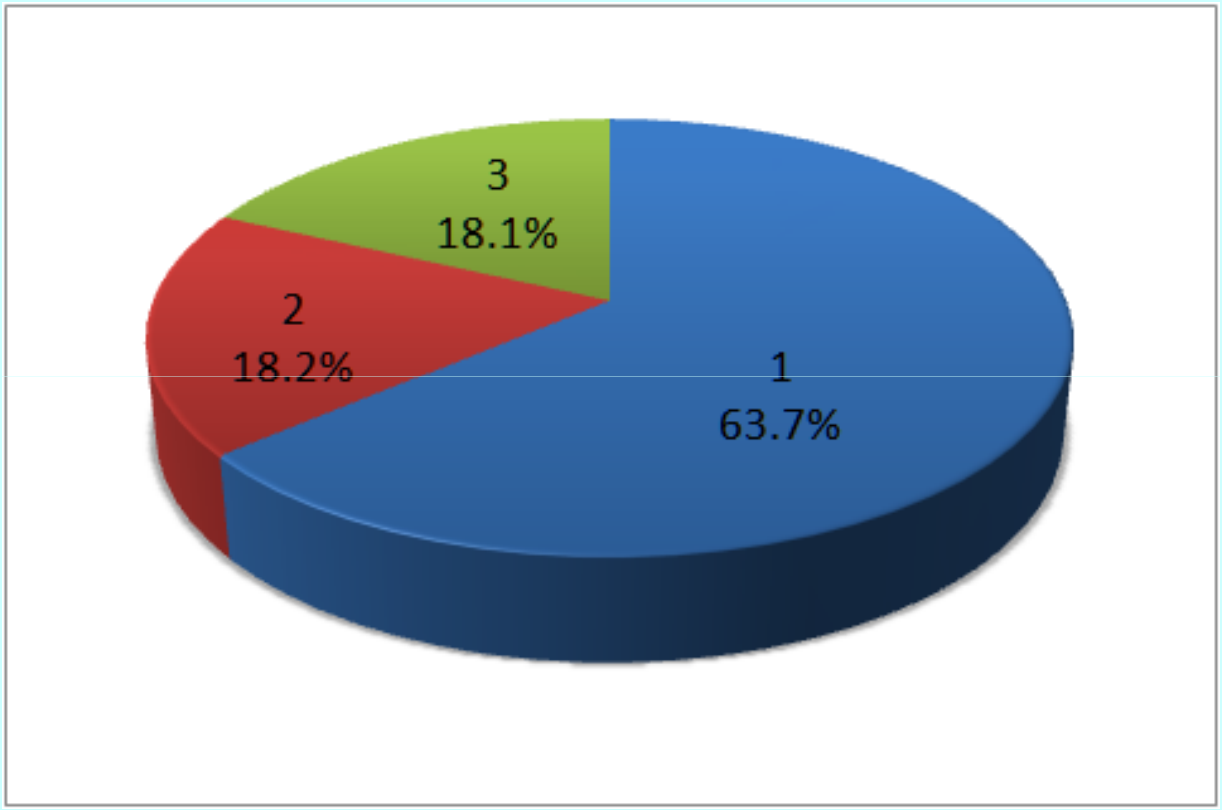
V.E. Messerle, **A.B. Ustimenko**

Combustion problems Institute, Research Institute of Experimental and Theoretical Physics, Almaty, Kazakhstan
ust@physics.kz

2nd World Congress on Petrochemistry and Chemical Engineering
Las Vegas, USA October 27-29, 2014

It is not the use of coal, but how the coal is used that must be the focus of action – World Coal Institute, London

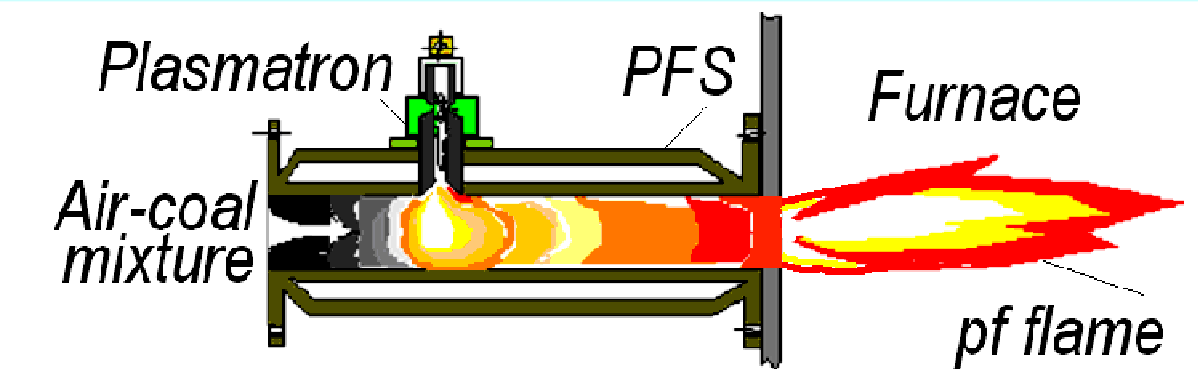
Proven reserves of fossil fuels worldwide



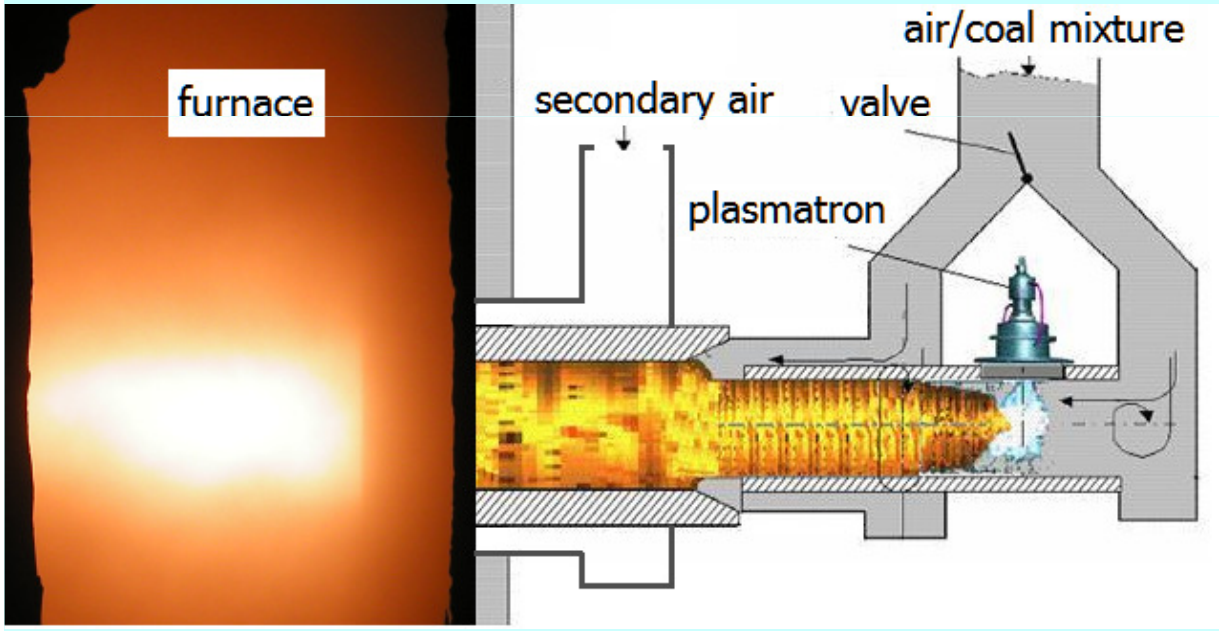
1 – coal, 2 – oil fuel, 3 – gas

British Petrol Statistical Review of World Energy, June 2011

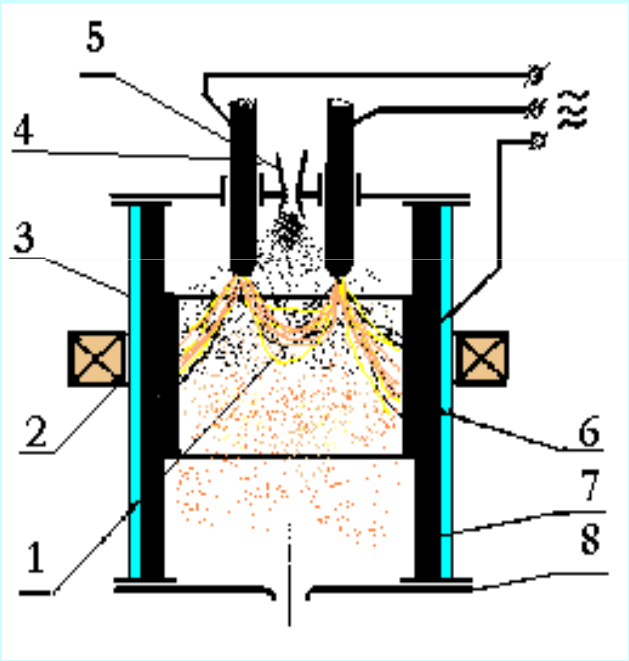
Plasma-fuel systems (PFS) for plasma-aided processing of fuel



Direct flow PFS for coal ignition

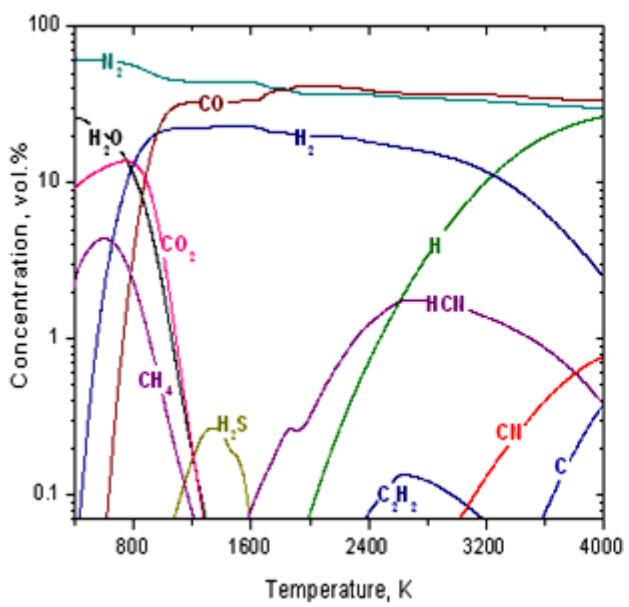


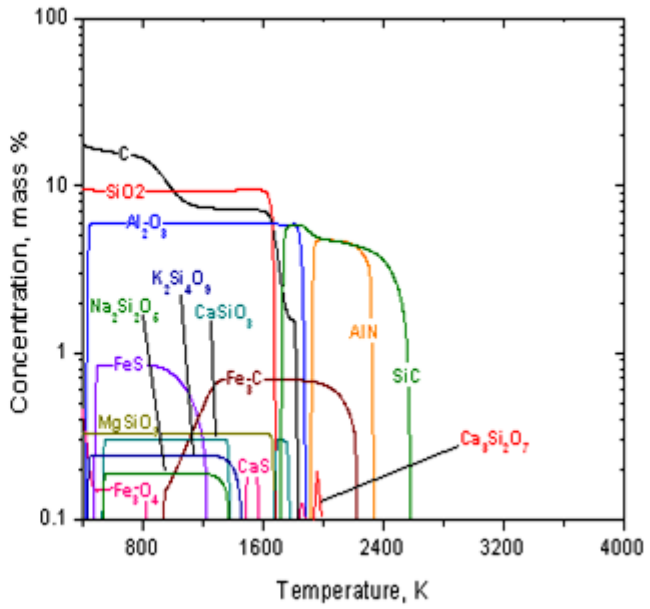
Vortex PFS for PF ignition

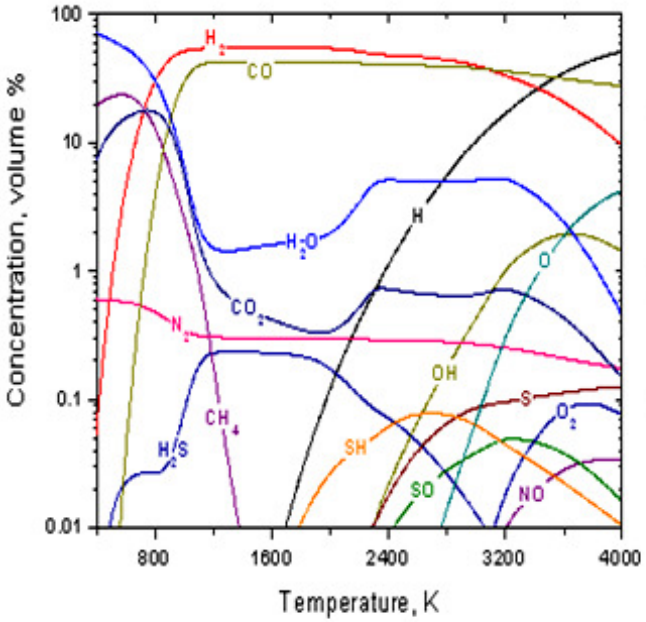


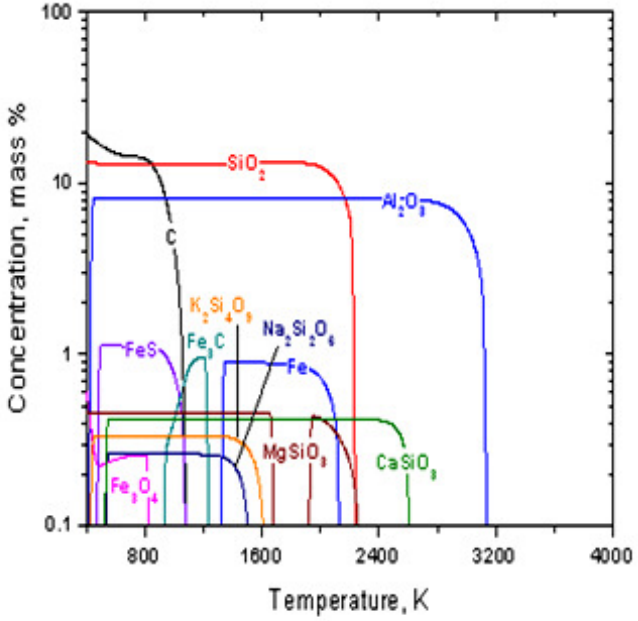
Direct flow PFS for plasma processing of fuel

BASIC PRINCIPLES OF THE PLASMA-FUEL SYSTEMS TECHNOLOGY





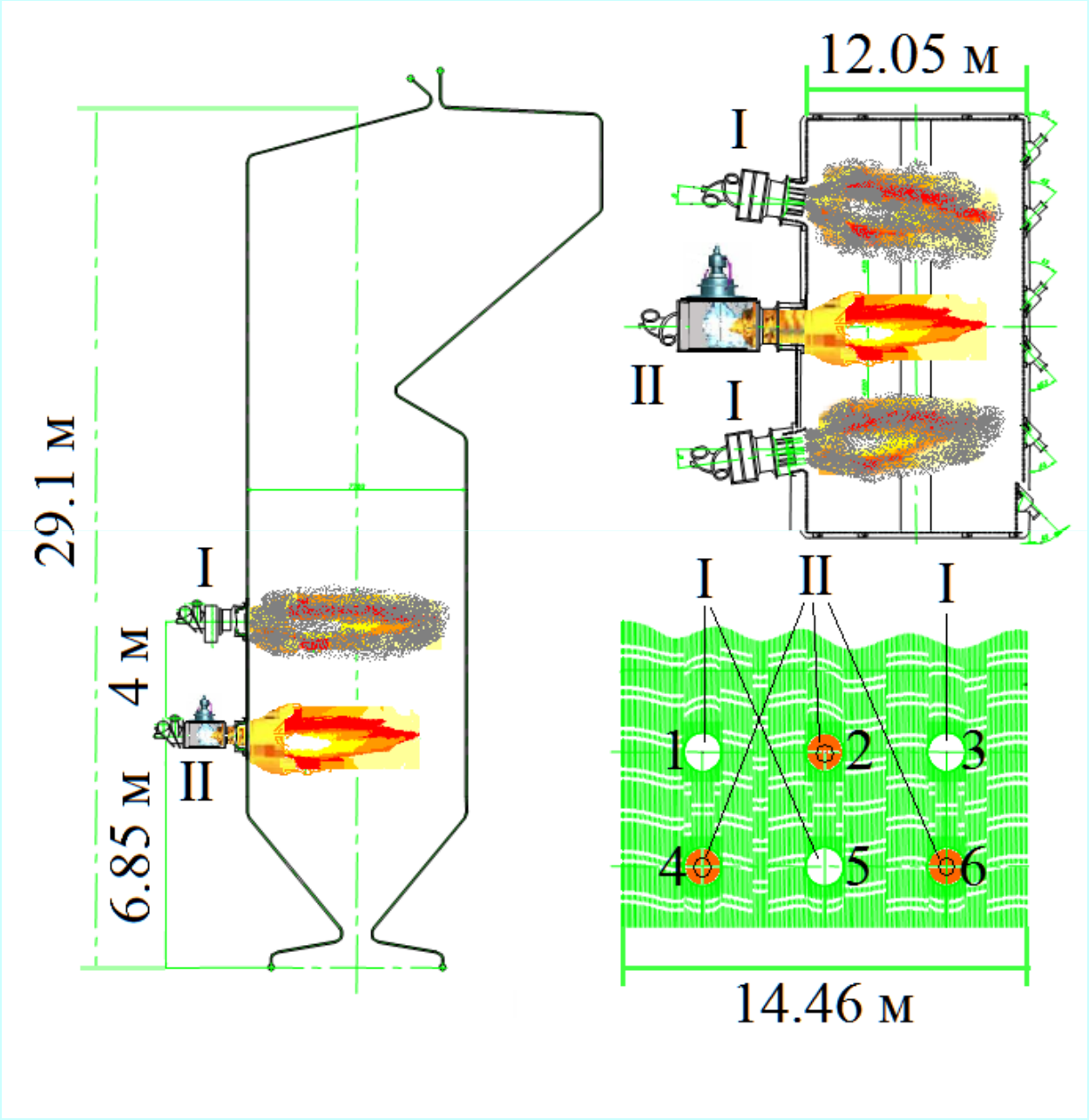




Thermochemical treatment of coal is realized in the PFS for rich coal/air mixtures (about 0.4-0.6 kg of coal per one kg of air: 1.0 of coal + 1.275 of air). From the low-rank coal highly reactive fuel is prepared.

Gasification of coal is realized in the PFS at coal/oxidant mixtures (1.0 of coal + 0.6275 of water steam). From the low-rank coal high calorific synthesis-gas is prepared.

PLASMA-FUEL SYSTEMS APPICATION AT TPP

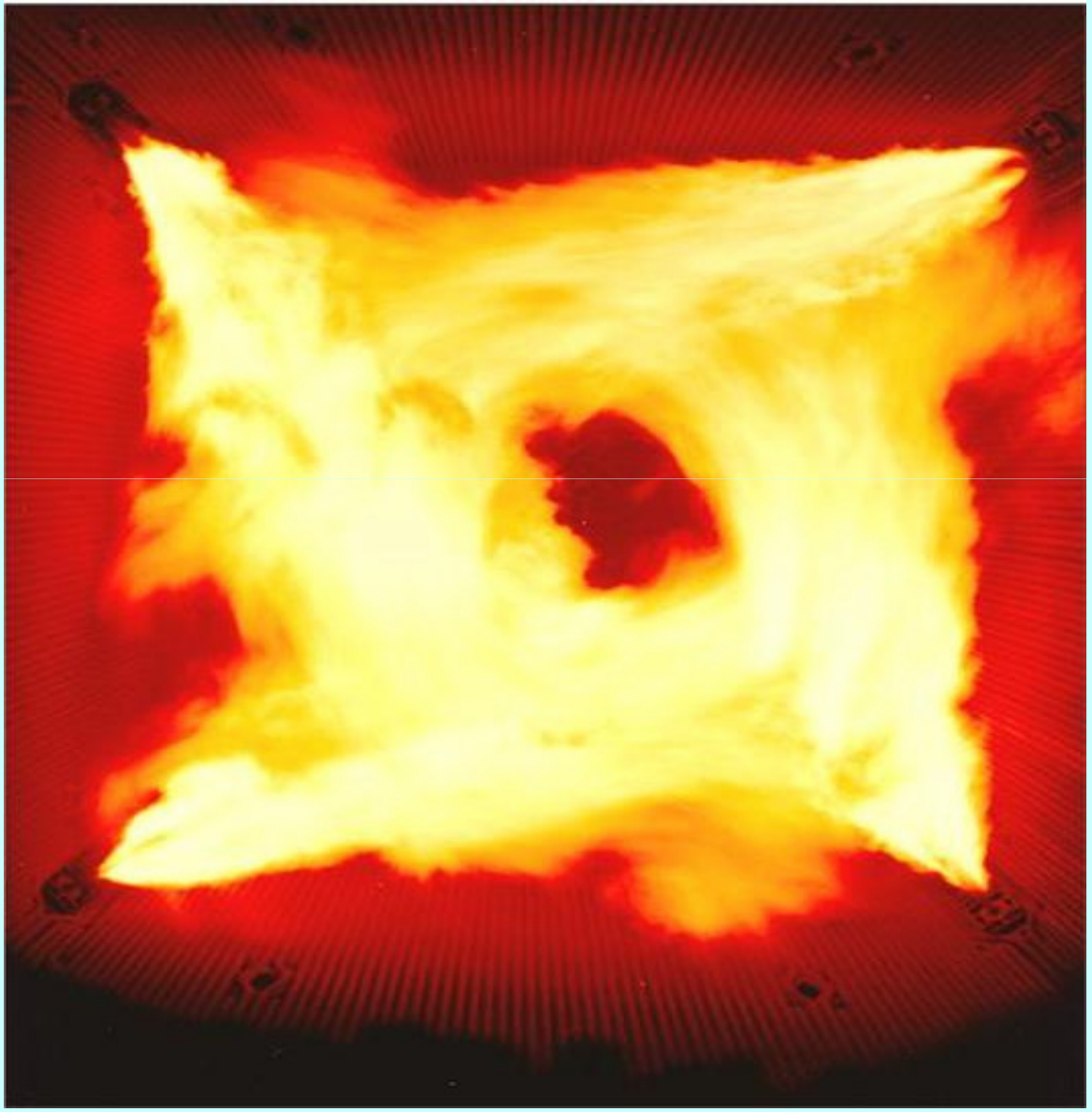


420 t/h steam boiler furnace equipping with PFS (Almaty TEC-2, Kazakhstan) :

1 – main pulverized coal burners,

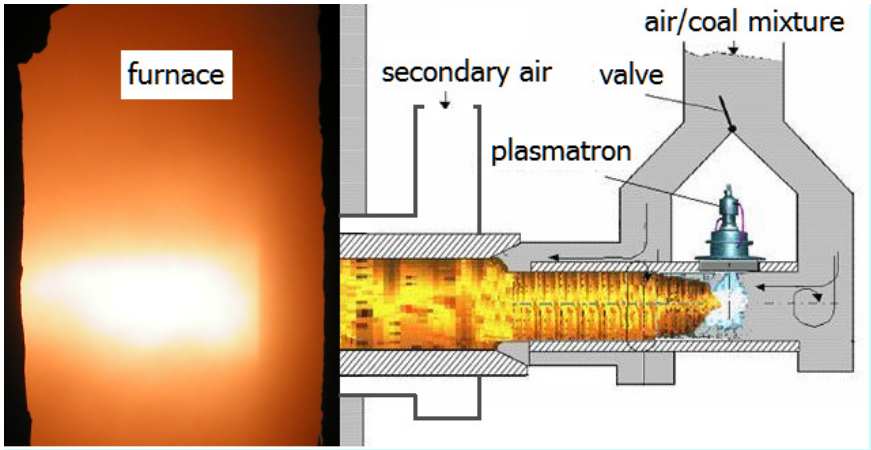
2 – PFS.

Conventional (fuel oil) start up of a pulverized coal boiler and pf flame stabilization

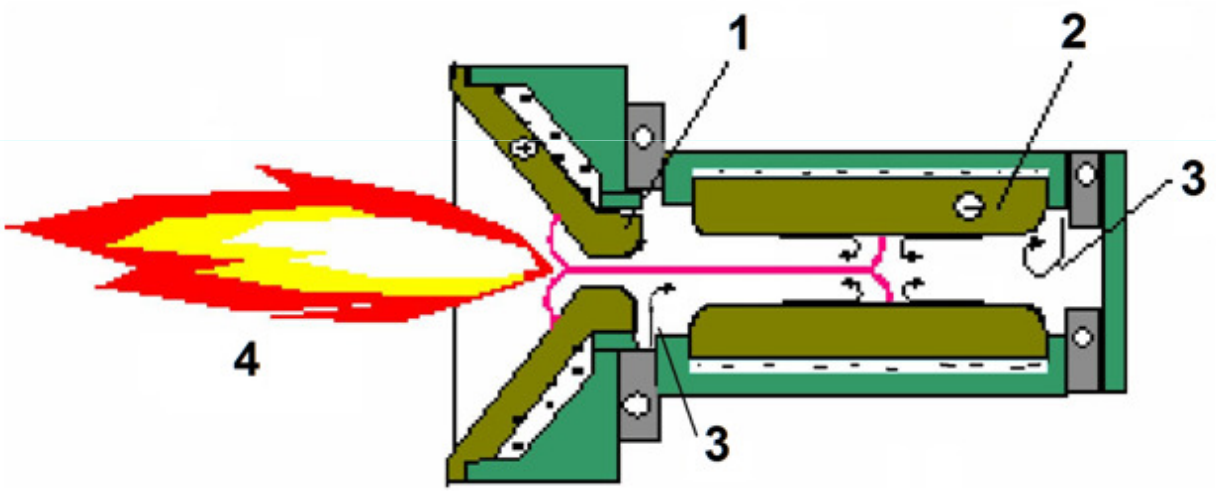


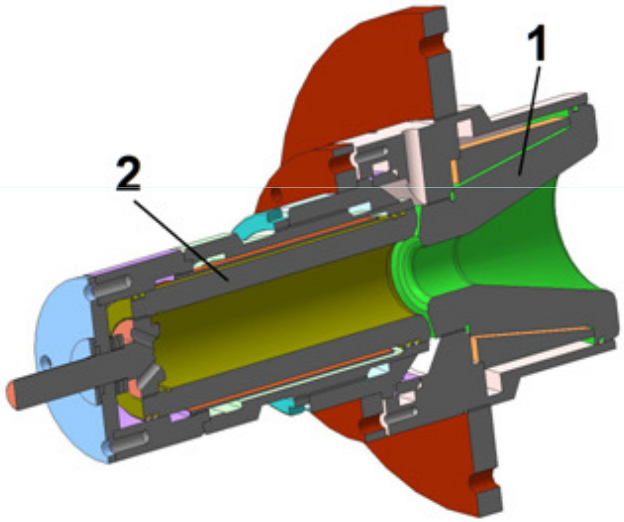
Fuel oil rate for different steam productivity pulverized coal boilers

Boiler steam productivity, t/h	Fuel oil rate for 1 start up, t
50-75	3-6
160-200	10-25
220-420	30-80
640-670	80-100
950	100-140
1650	150-250
2650	250-350



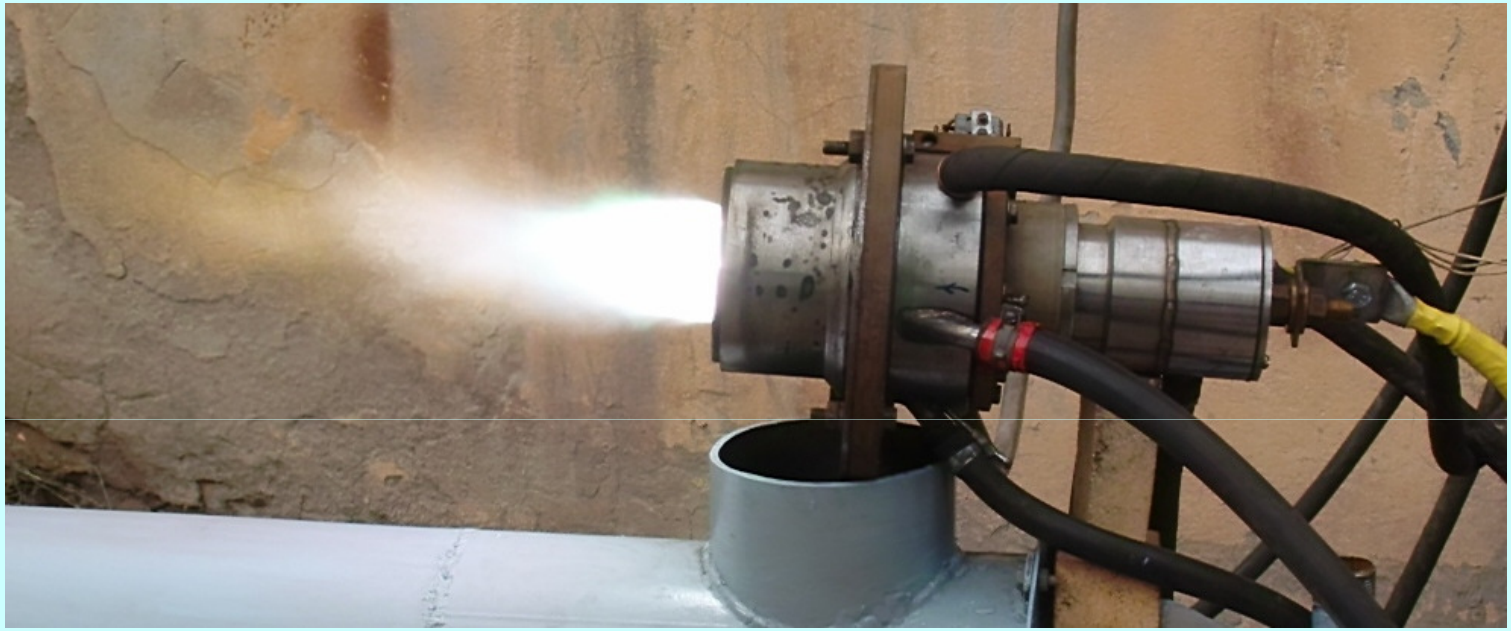
Plasma torch is the main element of PFS





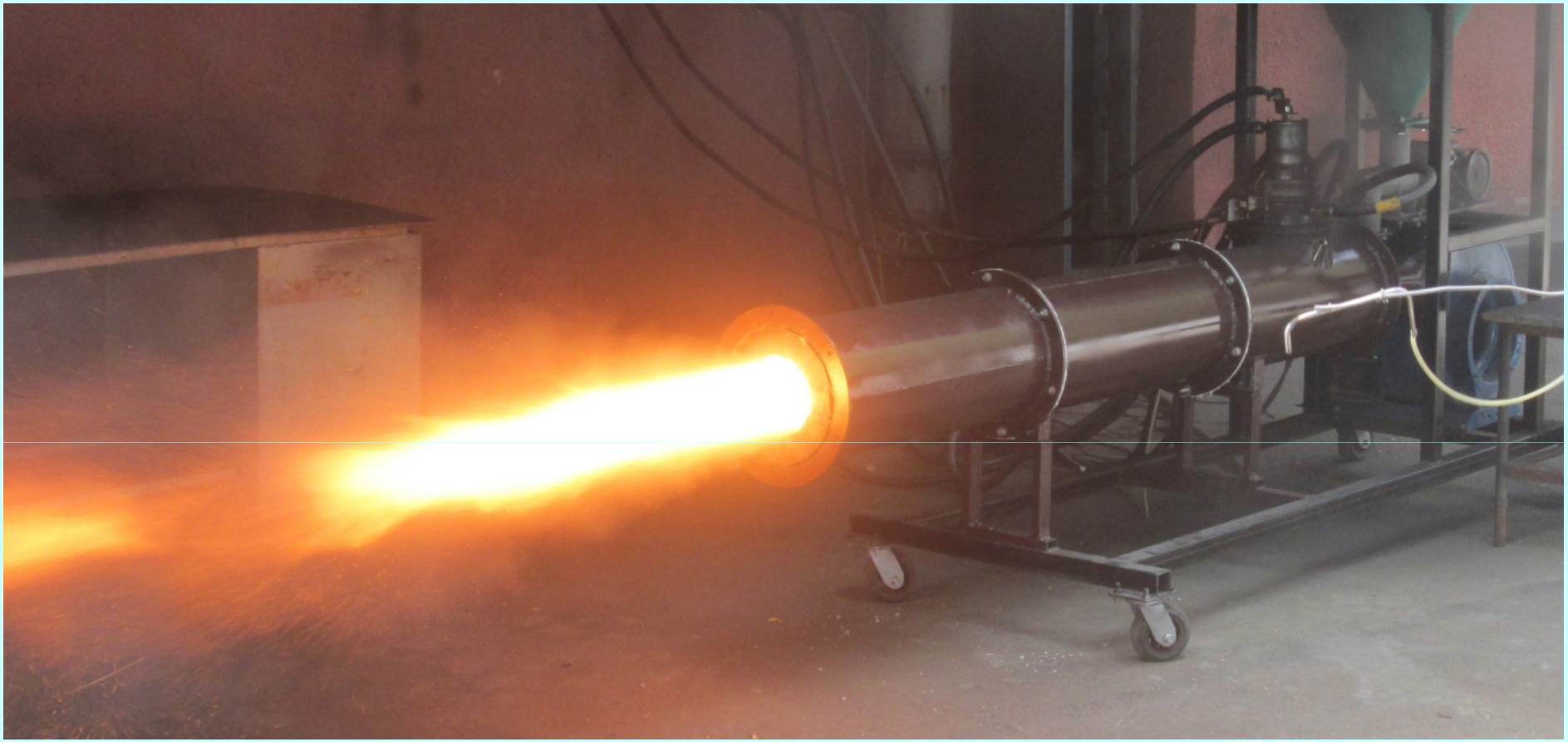
Sketch of the DC plasma torch:
1 – anode; 2 – cathode; 3 – air; 4 – plasma flame

Plasma torch is the main element of PFS



Testing of plasma torch for industrial application

EXPERIMENTAL PFS: IGNITION OF EKIBASTUZ COAL



Plasma torch power – 100 kW;
Consumption of pulverized coal – 1000 kg/h;
Temperature of the flame – 1180 °C.

PFS test at boiler BKZ-420 ATPP-2

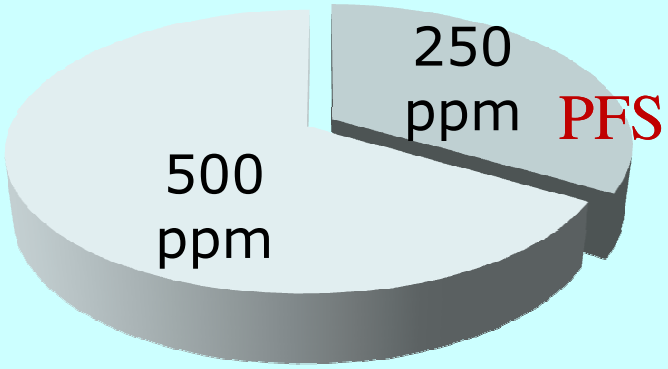


View of pf flame from PFS in boiler's window (8th minute of the start up, T=1070 °C)

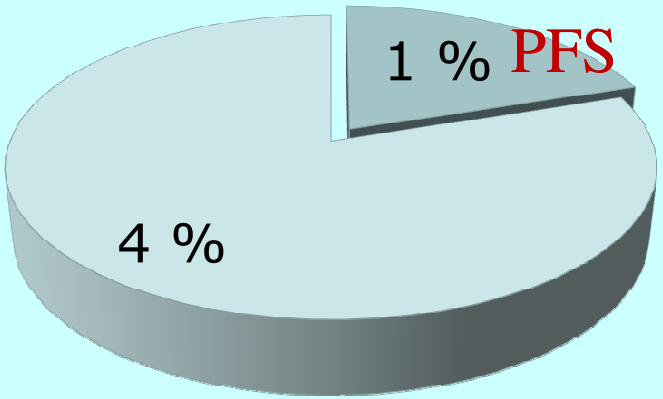
Concurrence

Conventional technology	Plasma technology
1. Fuel Oil Rate for Russian TPP	
5.1 mln. t/year (cost is more than $ 2.5 billion)	*0*
2. Fuel Oil Rate for Kazakhstan TPP	
~1 mln. t/year (cost is about $ 500 mln.)	*0*
3. Investments for TPP	
100%	*3-5%*
4. Operating costs	
100%	*28-30%*
5. Electric power consumption for TPP auxiliary	
3-5%	*0.5-1.0%*

NOx reduction



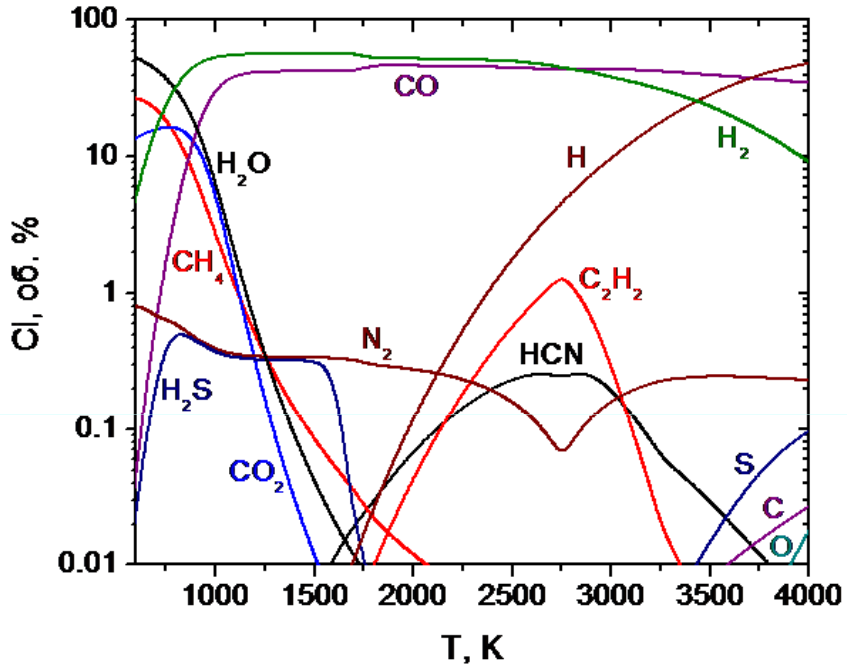
Unburned carbon reduction

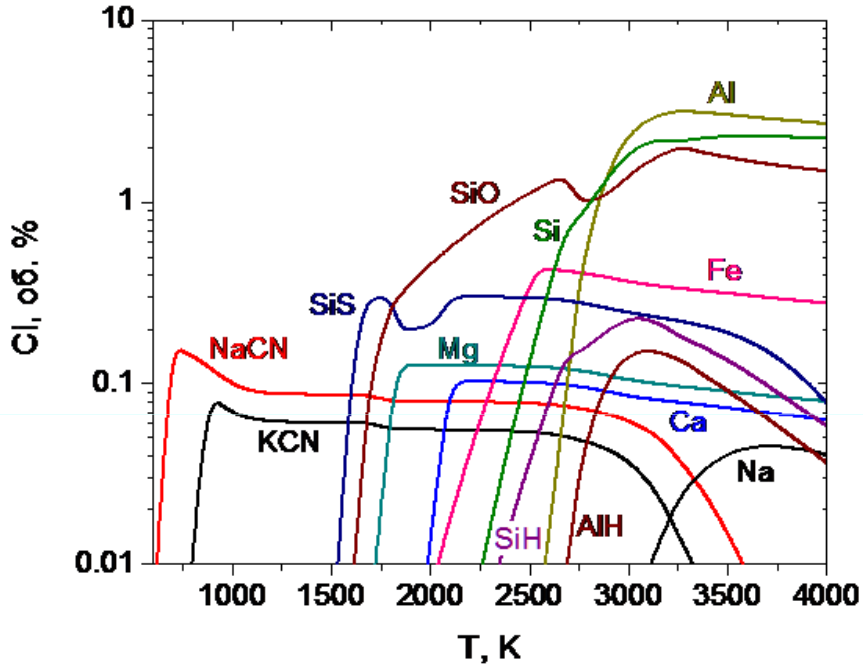


1 ton of fuel oil equivalent (by caloricity) to 2 tons of coal

1 ton of fuel oil equivalent (by price) to 20 tons of coal

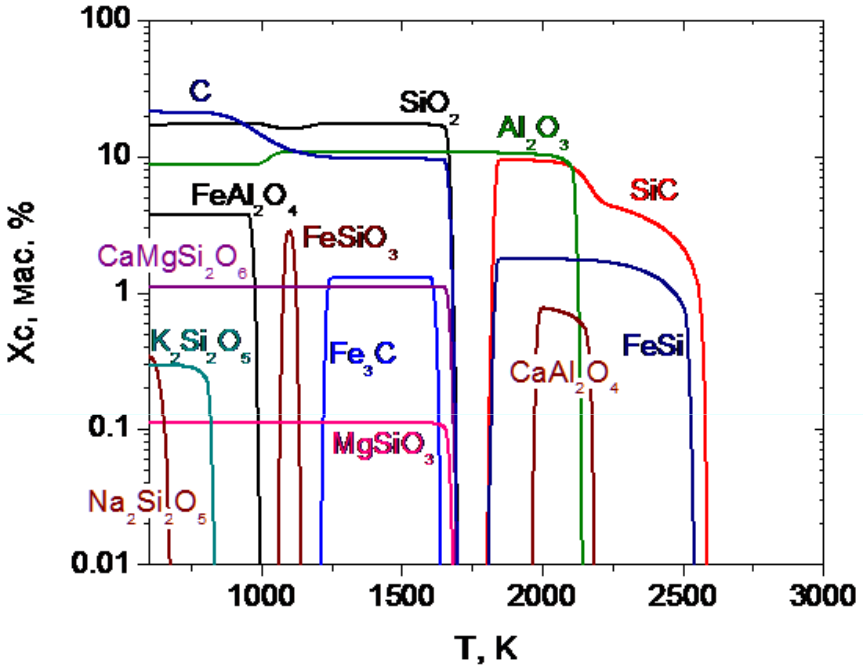
PLASMA GASIFICATION AND COMPLEX PROCESSING OF COAL

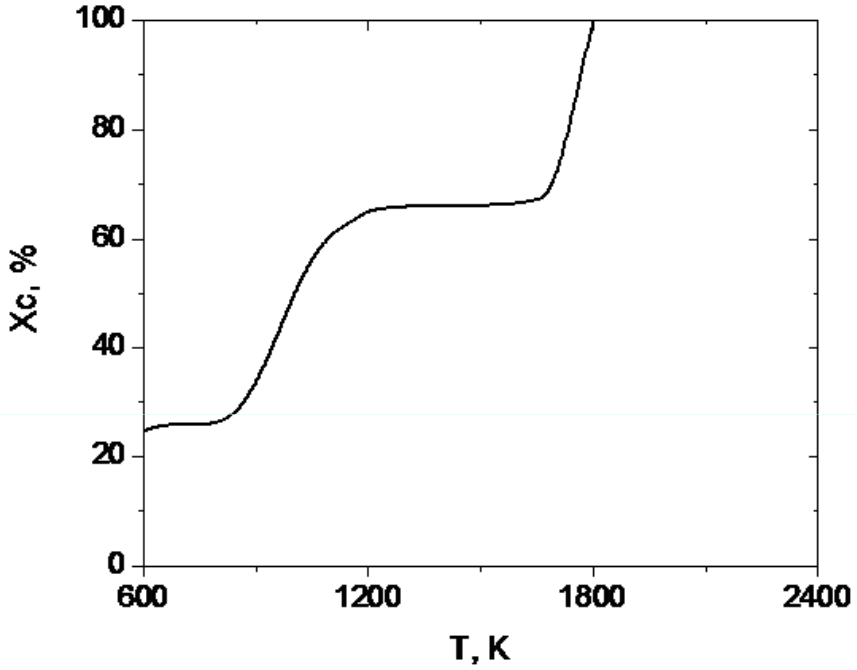




Temperature dependence of concentrations of organic and mineral components in gas phase at complex processing of coal

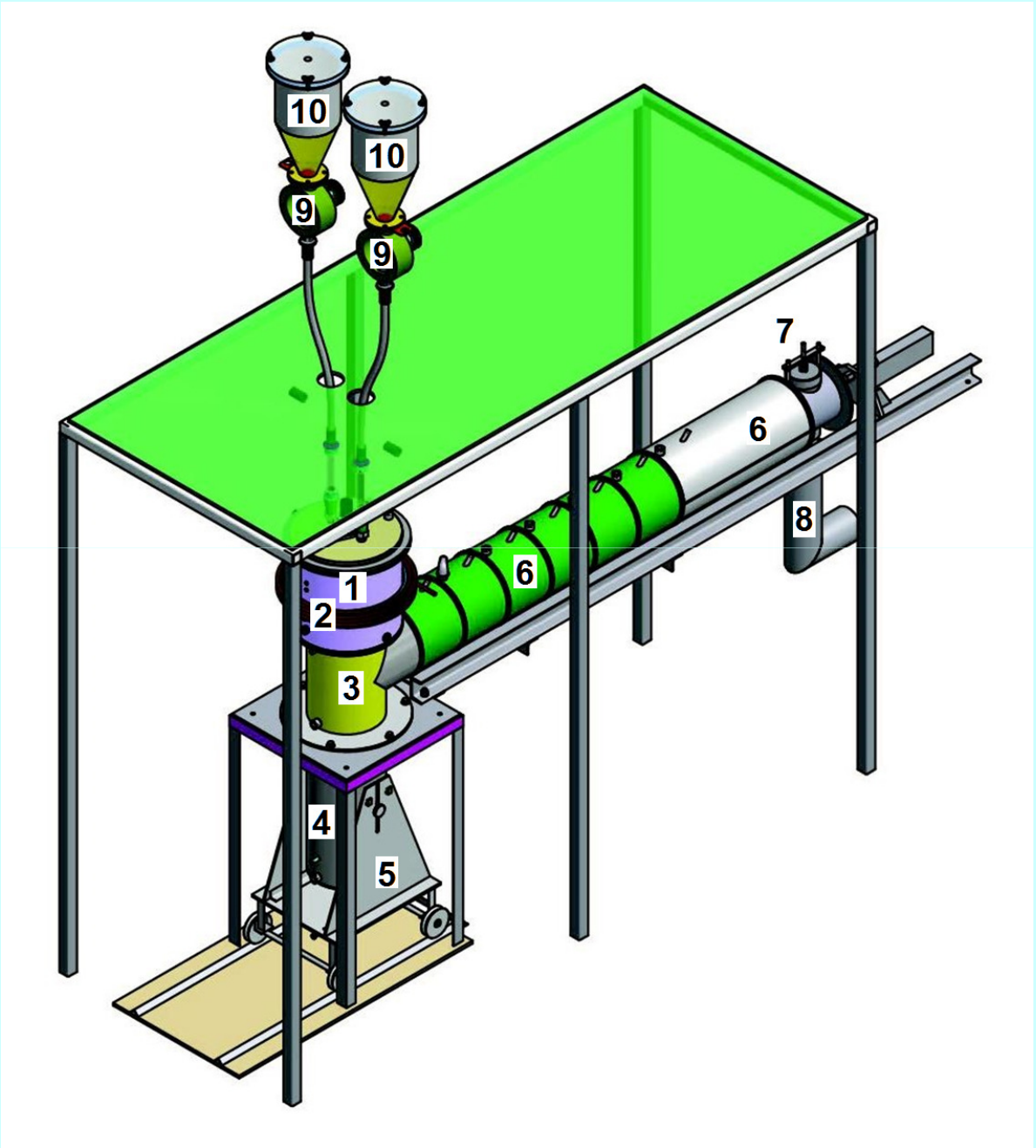
PLASMA GASIFICATION AND COMPLEX PROCESSING OF COAL





Temperature dependence of concentrations of components in condensed phase and coal gasification degree at complex processing of coal

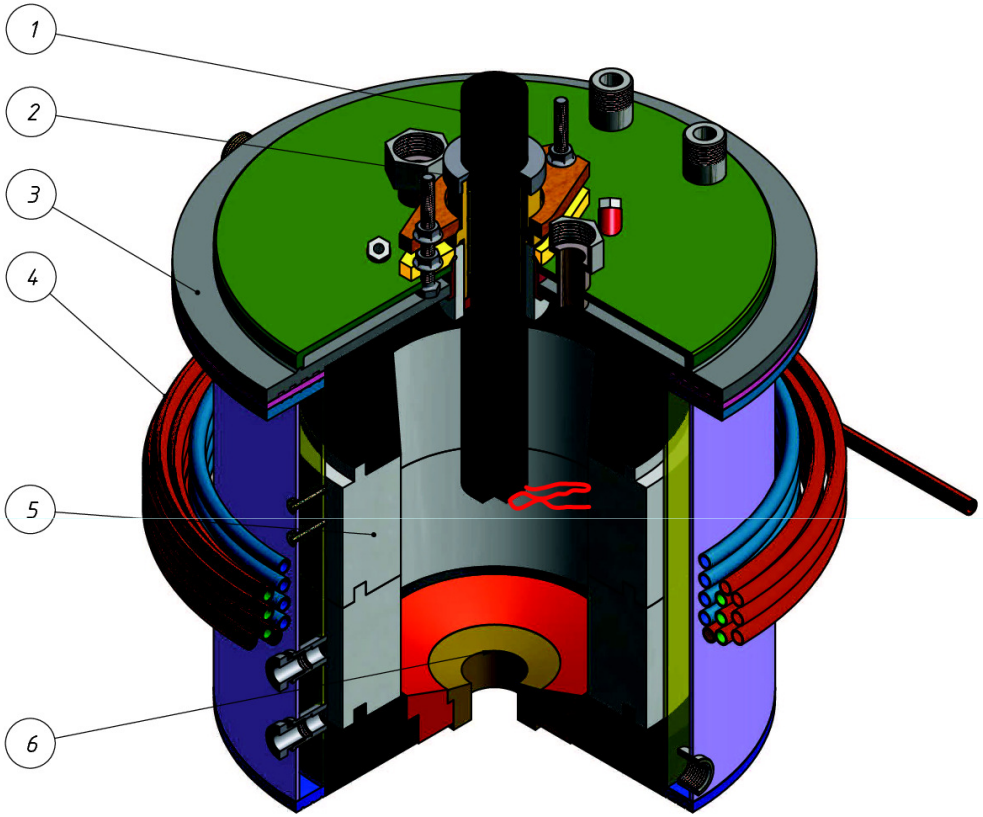
PLASMA GASIFICATION AND COMPLEX PROCESSING OF COAL

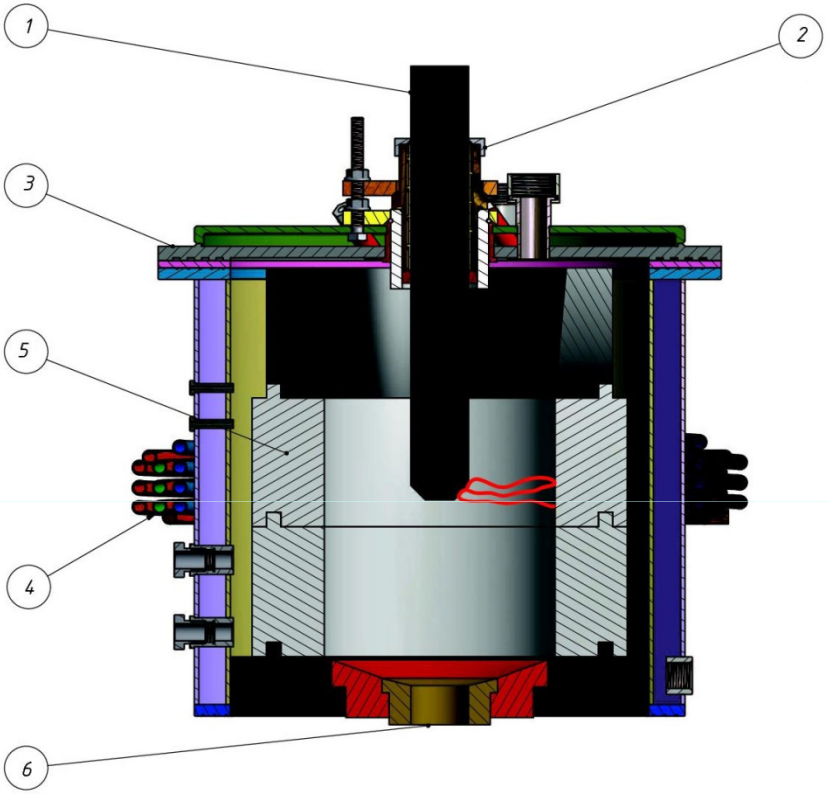


Layout of Plasma Installation for Gasification of Coal

1 – plasma gasifier; 2 – electromagnetic coil, 3 – chamber for gas and slag separation; 4 – slag catcher; 5 – stand for slag catcher; 6 – chambers of syngas sampling and cooling; 7 - safety valve; 8 - chamber of syngas removal; 9 – pulverized fuel feeders; 6 – solid fuel dust hopper

EXPERIMENTAL REACTOR FOR PLASMA GASIFICATION COMPLEX PROCESSING AND HYDROGENATION OF COAL





Scheme of Plasma Reactor

1 – rode graphite cathode; 2 – cathode insulator; 3 – water cooled cover;
4 – electromagnetic coil; 5 – ring graphite anode; 6 – graphite orifice

PLASMA GASIFICATION AND COMPLEX PROCESSING OF COAL



a



b

Plasmochemical reactor in operate mode (a) and view of the installation (b).

$$G2+G3+G4+G5=G6+G1+G7, [кг/ч]$$

$$P_{arc}+P1=P2+P3+P4+P5+P6, [кВт]$$

PLASMA GASIFICATION AND COMPLEX PROCESSING OF COAL

Solid fuels chemical analysis, % dry mass basis

Solid fuel	C	O	H	N	S	SiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Al_2O_3
KBC	48.86	6.56	3.05	0.8	0.73	23.09	2.15	0.34	0.31	0.16	0.15	13.8
CP	75.0	0.88	15.53	0.01	5.63	1.31	0.6	0.1	0.05	0.07	0.04	0.78
PBC	33.60	8.52	6.50	0.88	2.40	28.52	1.73	0.41	0.46	-	-	16.98
TBC	48.58	17.85	3.64	0.78	1.14	16.64	2.13	0.88	0.67	0.01	0.01	7.67

Ash content of CP – 3 %, PBC – 48.1 %, KBC – 44 % TBC – 28 %

Main Indexes of the Solid Fuels Plasma Gasification

N	Solid fuel	Consumption, kg/h		P, kW	SPC, kW h/kg	T_{AV}, K	CO	H_2	N_2	X_C, %
		fuel	steam				Volume %			
1	KBC	4.0	1.9	25	4.8	3500	41.5	55.8	2.7	94.2
2	CP	2.5	3.0	60	9.6	3850	36.2	63.1	0.7	78.6
3	PBC	7.6	2.7	60	5.83	2600	34.1	51.1	14.8	92.3
4	TBC	7.1	4.5	60	5.17	3100	45.8	49.4	4.8	93.2

PLASMA GASIFICATION AND COMPLEX PROCESSING OF COAL

Integral characteristics of low-rank coal (TBC) plasma gasification

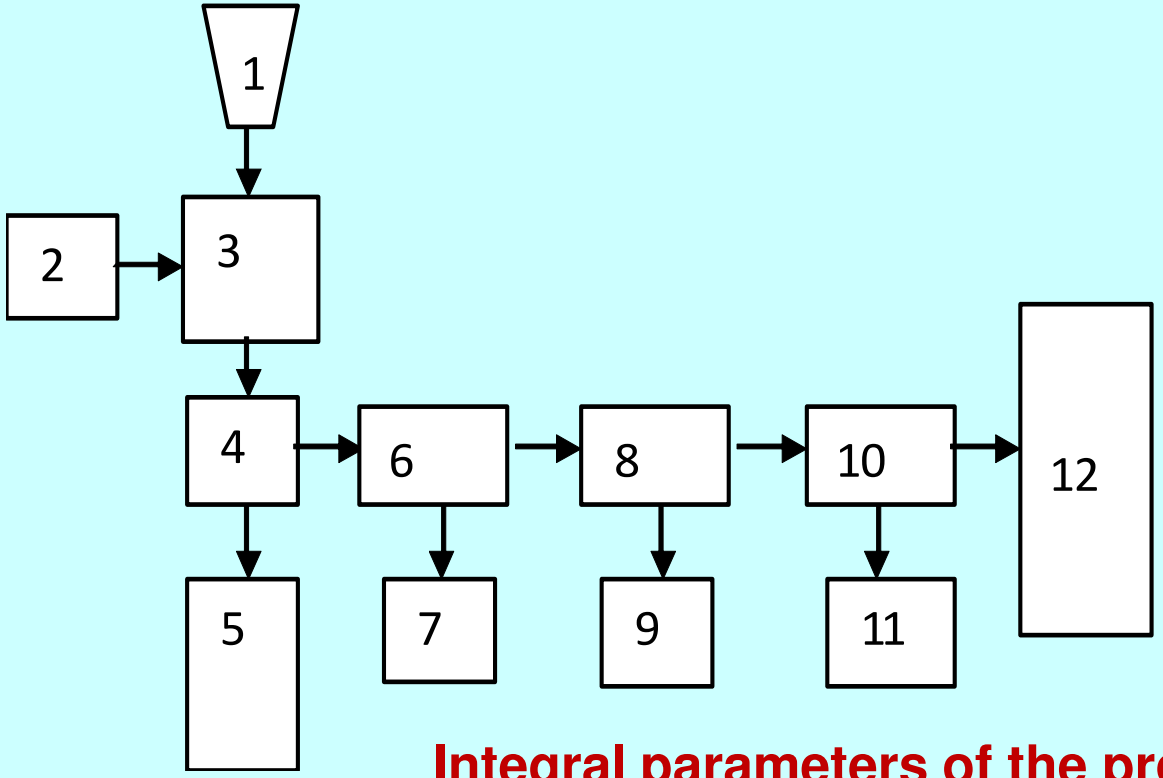
T, K	Q_{sp}, kW·h/kg	CO	H_2	X_C, %	X_S, %
		Volume %			
3100	5.36	45.8	49.4	92.3	95.2

Reduction degree (Θ) of mineral mass of coal

Place of sample	*T, K*	*Θ, %*
Slag from botm of the reactor	2600-2800	8.5-44.0
Slag from the wall of the reactor	2600-2900	16.5-47.3
Stuff from slag cather	2000-2200	6.7-8.3

$$C + H_2O = CO + H_2$$
$$M_nO_m + C = nM + mCO$$
$$Me_nO_m + C = nMe + mCO$$

BLOCK DIAGRAM OF PLASMA PROCESS FOR URANIUM, MOLYBDENUM AND VANADIUM EXTRACTING FROM COAL

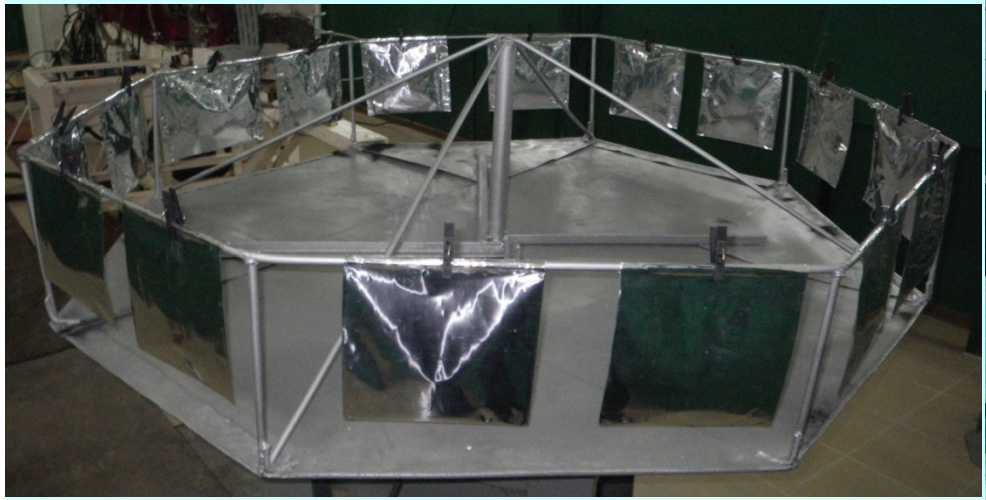


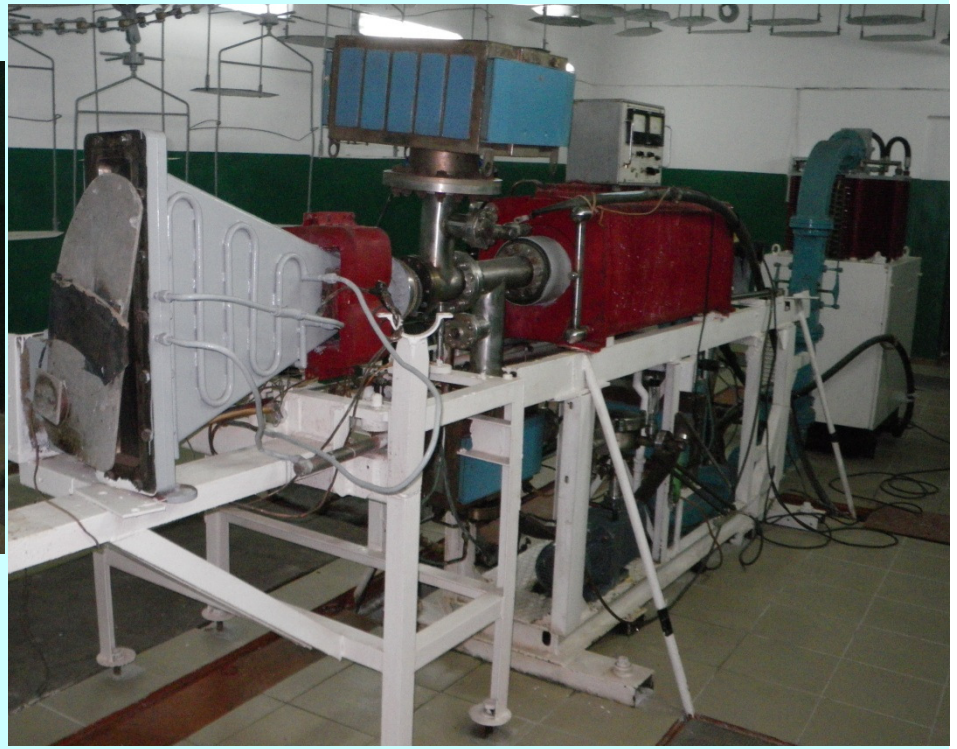
1 – coal dust hopper, 2 – water steam generator, 3 – plasmochemical reactor, 4 – chamber for gas and slag separation, 5 – clag catcher, 6, 8, 10 – heat exchanger, 7, 9, 11 – receiver, 12 – system for exhaust gas utilization.

Integral parameters of the process of plasma processing of uranium-bearing shale

No	G_f, kg/h	G_{steam}, kg/h	T_{av}, K	Q_{sp}, kW h/kg	X_U, %	X_{Mo}, %	X_V, %	X_C, %
1	5.82	0	2900	2.84	48.0	54.5	58.6	56.2
2	8.40	0	2500	1.93	25.7	34.5	41.7	54.6
3	6.60	0.60	2700	2.20	78.6	79.0	81.3	66.4
4	4.33	0.40	3150	3.04	23.6	24.3	29.0	70.4

Radiation processing of coal dust on the electron accelerator ELU-6 activated by an electron beam





The irradiation dose is 5 Gray

PLASMA HYDROGENATION OF COAL

Integral characteristics of plasma hydrogenation of low grade coal

G, kg/h		Parc, kW	Ci, % on mass basis					T_{av}, K	Xc, %
Coal	Gas		C_2H_2	C_2H_4	C_2H_6	H_2	CO		
3.0	0.36	50	30.0	10.0	50.0	0.17	9.83	2900	84.7
3.0	0.42	55	30.4	10.1	50.5	0.2	9.0	3200	88.5

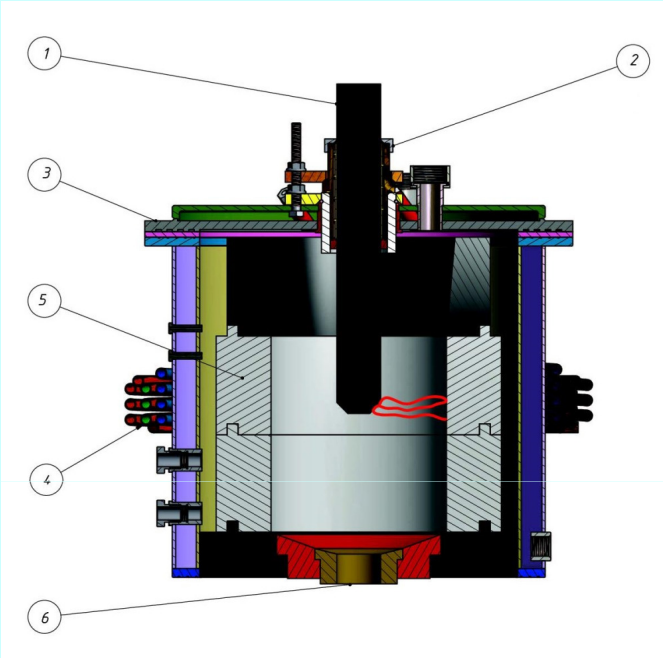
HYDROGEN AND TECHNICAL CARBON PRODUCING BY PLASMA CRACKING OF HYDROCARBON GAS

$$CH_4+H_2O=CO+3H_2$$

$$C_nH_m=C_n+H_m$$

$$C_3H_8=3C+4H_2$$

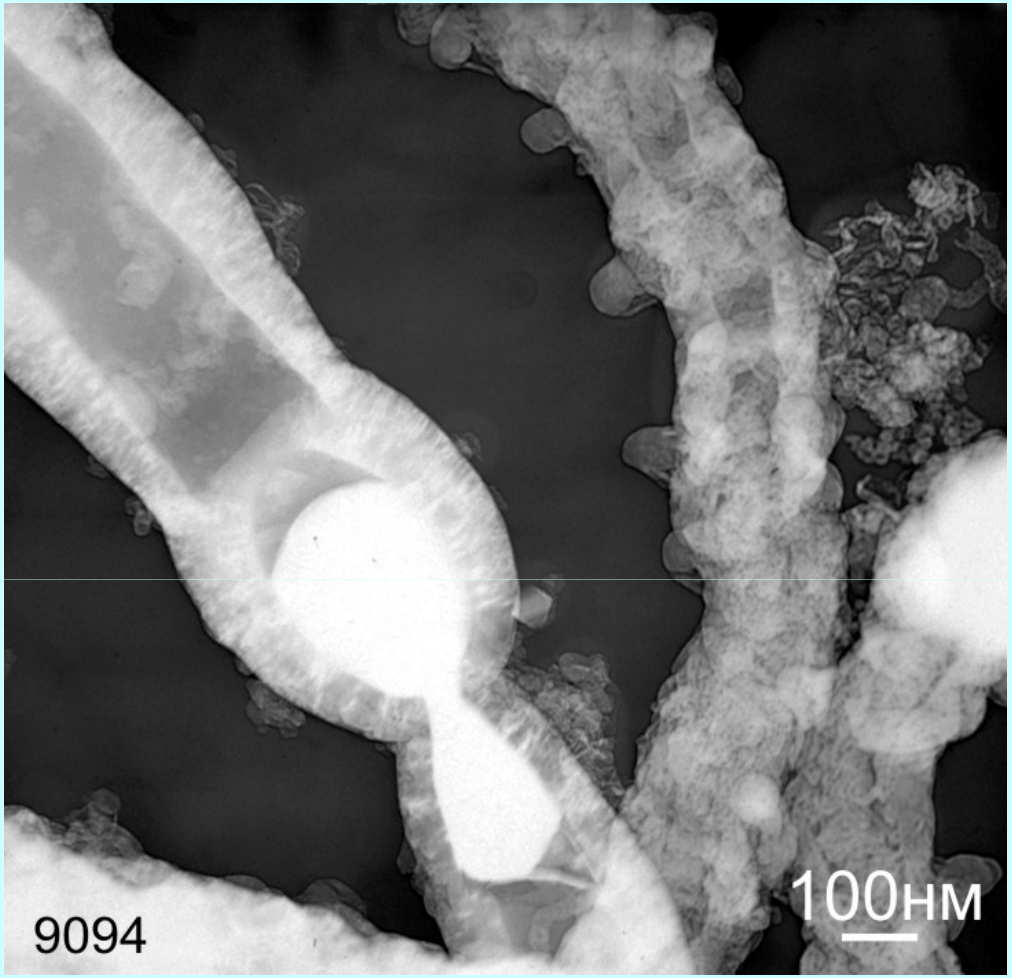
$$C_4H_{10}=4C+5H_2$$



PLASMA CRACKING OF PROPANE-BUTANE MIXTURE

Gas flow - 300 l/h, electrical power of the reactor – 60 kW.
Productivity of a pilot installation of 1MW power – 330 Nm^3/h.
74% of technical carbon (171 kg/h) can be produced and
25% of hydrogen (58 kg/h).

PLASMA CRACKING OF PROPANE-BUTANE MIXTURE



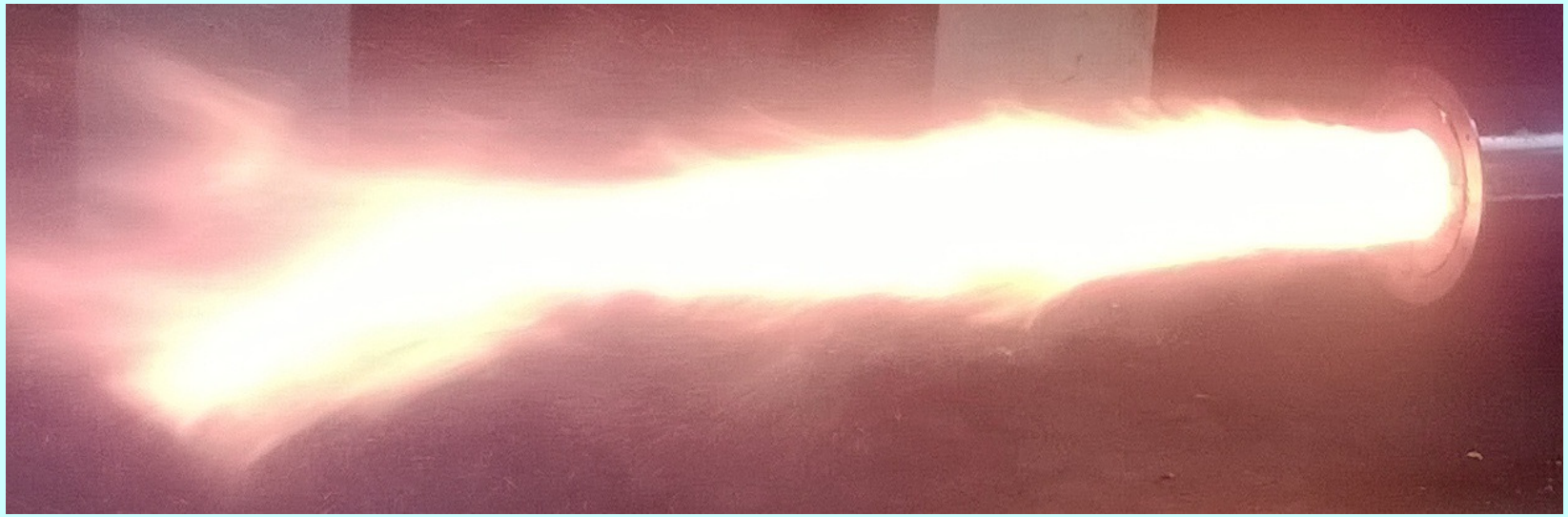
Images of a sample of the products of propane-butane plasma pyrolisis through transmission electron microscope – colossal carbon nanotube metal nanoparticle intercolated.

CONCLUSION

The optimal ranges of recommended process parameters for plasmochemical processing of fuel

Fuel / plasma forming gas	*T, K*	*Specific power consumption, kW·h/kg of fuel*	*Fuel conversion rate, %*	*Concentration mg/Nm³*	
				NO_x	SO_x
1. Plasmochemical preparation of coal for combustion (air)					
1.5–2.5	800–1200	0.05–0.40	15–30	1–10	1–2
2. Complex processing of coal (water steam)					
1.3–2.75	2200–3100	2–4	90–100	1–2	1
3. Plasma gasification of coal (water steam)					
2.0–2.5	1600–2000	0.5–1.5	90–100	10–20	1–10
4. Radiant-plasma processing of coal (air)					
1.5–2.5	800–1200	0.1–0.45	22–45	1–10	1–2
5. Plasma processing of uranium-bearing solid fuels (water steam)					
8-12	2500-3150	2–4	55-70	1-3	1-2
6. Plasmochemical hydrogenation of coal (hydrogen)					
10	2800–3200	6.5–8	70–100	0	0
7. Plasmochemical cracking of a propane-butane mixture					
18 м³/ч	1500–2500	2.2–3.8	98–100	0	0

PLASMOCHEMICAL PREPARATION OF COAL FOR COMBUSTION



Flame of highly reactive two-component fuel from high-ash Ekibastuz coal

Gas composition vol.%:

CO = 33.0

H_2 = 22.5

N_2 = 43.9

NOx < 15 ppm

SOx < 20 ppm

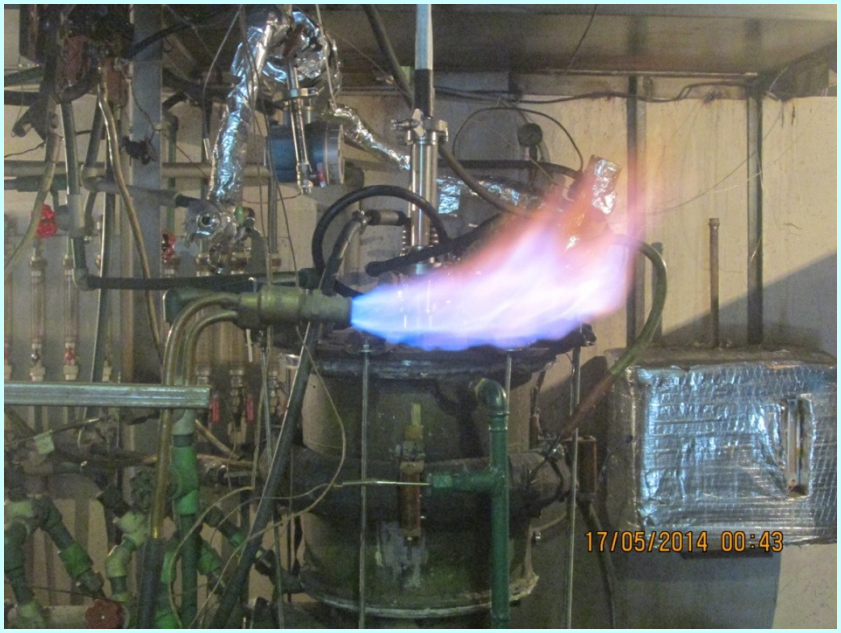
COMPLEX PROCESSING OF COAL



Flame of syngas from high-ash Kuuchekinskiy coal

Gas composition vol.%:
CO = 46.9
H_2 = 52.3
N_2 = 0.8
NOx < 15 ppm
SOx < 20 ppm

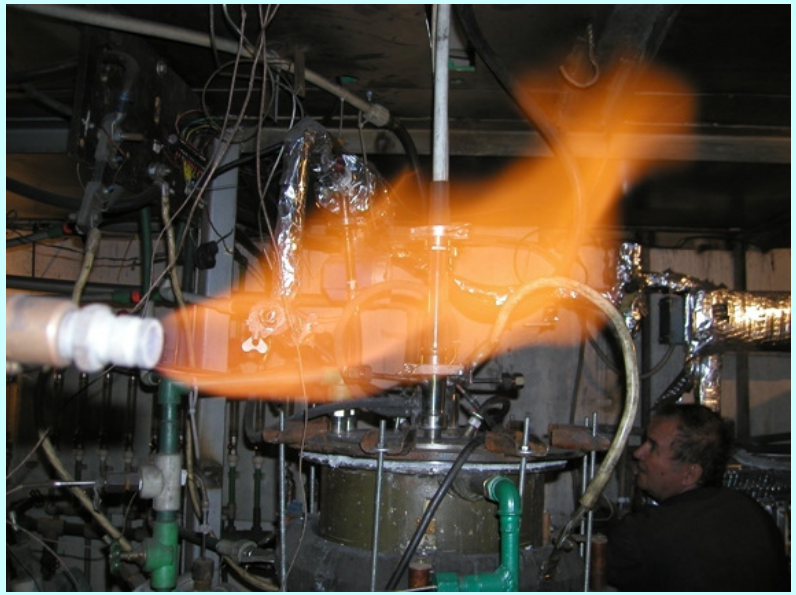
PLASMA STEAM GASIFICATION OF COAL



Flame of syngas from uranium-bearing coal Kulan-Komir

Gas composition vol.%:
CO = 41.4
H_2 = 56.9
N_2 = 1.7
NOx < 15 ppm
SOx < 20 ppm

RADIANT-PLASMA PROCESSING OF COAL



Flame of syngas from radiated high-ash Kuuchekinskiy coal

Gas composition vol.%:

CO = 37.5

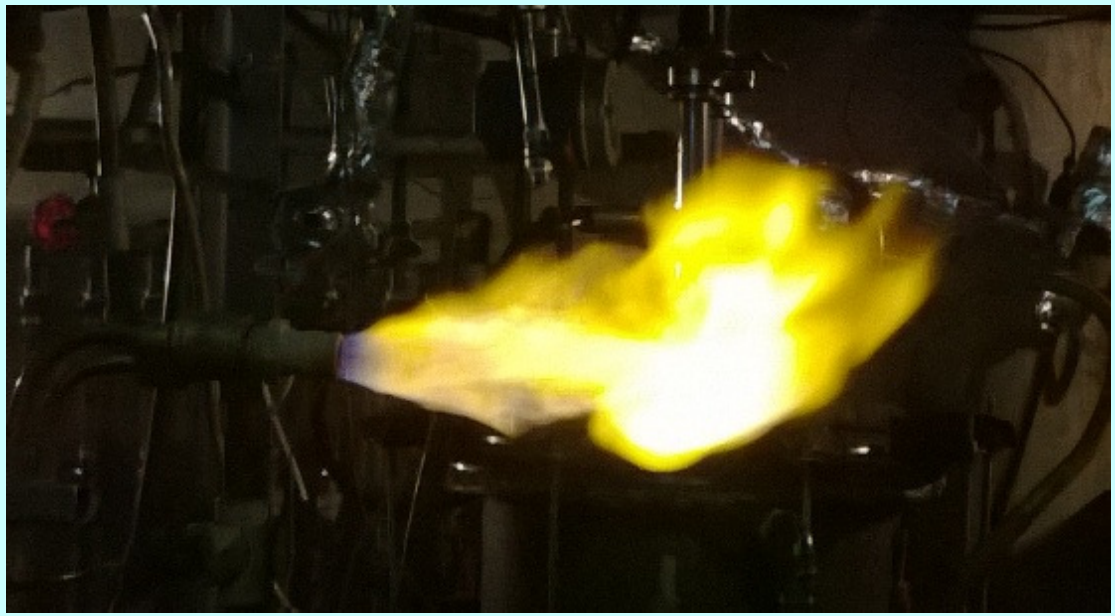
H_2 = 57.7

N_2 = 4.8

NOx < 15 ppm

SOx < 20 ppm

PLASMOCHEMICAL HYDROGENATION OF COAL



Flame of syngas from Kuuchekinskiy coal

Gas composition vol.%:

C_2H_2 – 30.1

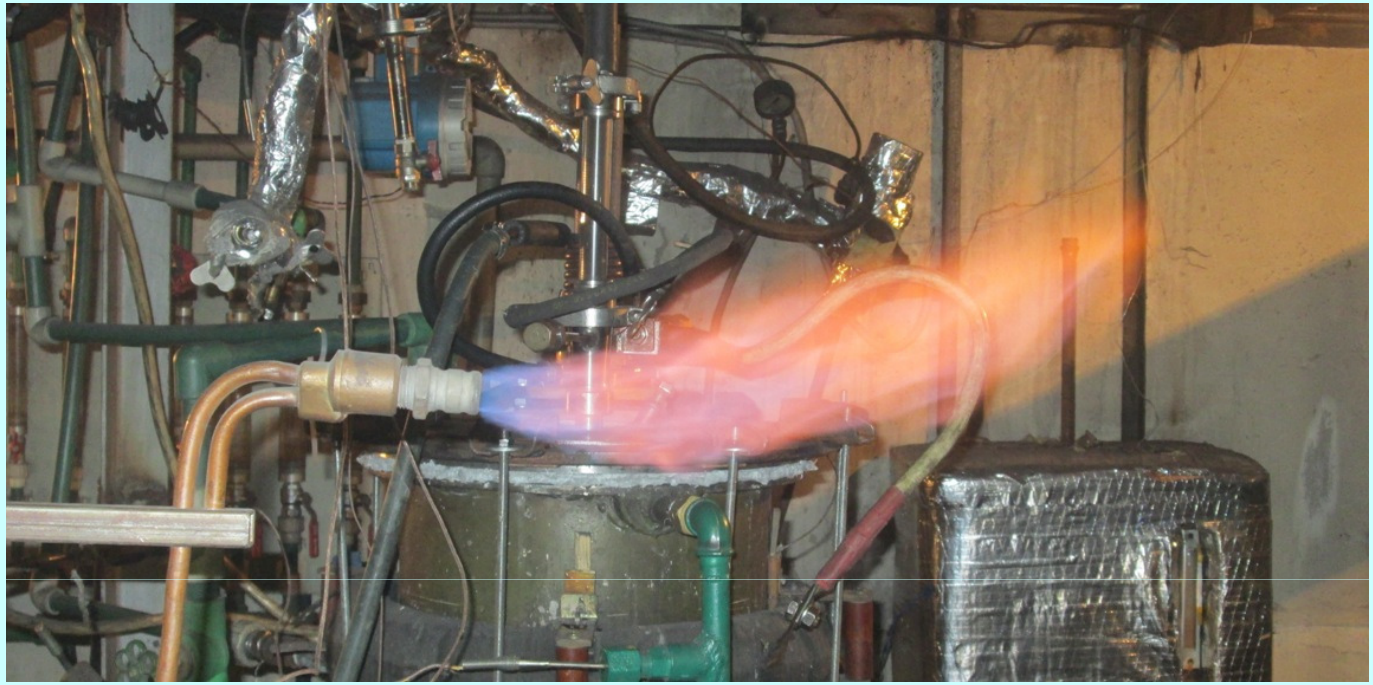
C_2H_4 – 9.9

C_2H_6 – 50.0

CO – 5.6

N_2 – 4.4

PLASMOCHEMICAL CRACKING OF A PROPANE-BUTANE MIXTURE



Flame of syngas

Gas composition vol.%:

H_2 – 97.0

CH_4 – 1.0

CO – 0.7

N_2 – 1.3

Thanks !