Plasma Technology of Coal Gasification

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Utility boiler operators seeking to gain the greatest economic advantage from their units are faced with three challenges, namely the obligatory light-up fuel costs, the additional expense of supplementary fuel firing should they wish to use a cheaper fuel that may be beyond the original burner manufacturer's stability and combustion performance assurances and the immediate environmental impact of both. The novel use of plasma arc technology can provide a solution to these challenges. This paper introduces the work being undertaken through a joint collaboration between the EU, Kazahkstan and Russia in order to develop a tried and tested engineering methodology and a mathematical based application and sensitivity analysis approach for the design and optimisation stage of these plasma devices that, as a consequence, their assist in their universal introduction.

Keywords : plasma reactor, coal, gasification, numerical simulation, environmental impact

1. INTRODUCTION

Among new technologies, directed on cardinal decision of the problem of effective utilisation inferior coals under acceptable ecological parameters is preliminary gasification of solid fuels with application plasma reactors. This process is connected to reception in uniform plasma technological space of ecologically pure fuel synthesis-gas, free from ash particles, nitrogen and sulphur oxides, that is rather urgent for regions with the special requirements to observance of the ecological specifications.

Development of energetically effective and ecologically pure plasma technology of power coals gasification is not available without mathematical modelling of the process. Use of plasma gasificators is rather perspective for energetics and metallurgy. However, the absence of engineering methods of their computation complicates optimisation and designing of plasma generators, let alone their wide introduction.

2. NUMERICAL SIMULATION

For investigation of the process and computation of experimental unit the coal-dust plasma gasification modernised mathematical model was used [1,2].

Coal-dust plasma gasification mathematical model describes two-phase (coal particles and gas-oxidiser), chemically reacting flow, which is spread in reactor with internal heat spring (electric arc). Coal particles and gas are got into reactor with equal temperatures. There is heatmass exchange particle-to-particle gas-to-particle and gas-to-electric arc. Besides heat and impulse exchange between the flow and the wall of the reactor is accounted. Also some chemical fuel transformations are considered. They are formation of primary volatile products, conversation of evolved volatile products in the gas phase and coke residue gasification reactions.

The following assumptions were made in the formulation of mathematical description of the process of coal-dust gasification:

(a) the process is one-dimensional and steady-state;
(b) the equation of state of an ideal gas is assumed to hold;
(c) a homogeneous mixture of gas and particles is assumed at the reactor inlet;
(d) local heat transfer between the gas and solids includes connective and conductive components;
(e) the temperature gradients within the particle are negligible, and the temperature is uniform throughout the particle;
(f) the heat of reaction of the solid-gas phase reaction affects the temperature of the solids only, while that of the gas-phase reaction affects the gas-phase temperature only;
(g) particle-particle interaction and solid-wall friction are neglected due to the dilute system;
(h) viscosity effects are appreciable only in the gas-solid phase interaction;
(i) ash is inert component.

These assumptions make it possible ordinary differential equations using, which substantially simplifies the computation of the processes heat exchange and hydrodynamics and still allows a detailed description of chemistry of the process.

For the construction of a reliable mathematical model of polydisperse coal particle gasification, the set of equations must include equations for component concentrations (chemical kinetics equations) in conjunction with equations for gas and particle velocities and temperatures, respectively.

The model developed is distinguished by its detailed description of the kinetics of chemical reactions whose general scheme, along with the reactions of evolution of primary products, takes into account the reactions of their further transformation. The temperature dependence of rate constants is governed by the

Arrhenius equation: $k_j = A_j \cdot \exp\left(-\frac{E_j}{RT}\right) \cdot T^n$.

In the model fifty reactions are considered.

The calculations of the coal gasification processes so as experiments were performed for flow rates of coals, water vapour and electric power are given in the tables 1-3.

As a result of computation the figures like following were done (Figures 1-4).

Table 1. Chemical analysis of coals, mas.%.

A^d(%)	C	O	H	N	S	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
1. Kansko-Achinsk coal										
12.7	60.87	20.33	3.88	1.43	0.79	6.23	2.68	1.30	2.0	0.49
2. Turgay coal										
26.8	48.54	18.33	3.63	0.78	1.87	15.4	7.85	2.05	0.8	0.65
3. Podmoskovnyi coal										
48.1	33.6	8.52	6.5	0.88	2.4	28.52	16.98	1.73	0.41	0.46
4. Tugnuisk coal										
19.4	67.3	8.91	3.3	0.7	0.4	11.3	4.3	K_2O 0.48 Na_2O 0.6	1.5	0.7
5. Ecibastus coal										
45.05	38.7	6.07	2.6	0.63	0.7	29.2	13.9	1.24	0.34	0.37

Table 2. Chemical composition of coals for the computation, mas.%.

Ash	**C**	**H_2**	**H_2O**	**CO**	**CO_2**	**CH_4**	**C_6H_6**
1. Kansko-Achinsk coal							
12.7	40.8	0.1	13.9	9.8	2.2	2.5	18.2
2. Turgay coal							
28.0	32.7	1.0	4.0	6.92	15.2	5.9	6.28
3. Podmoskovnyi coal							
48.0	24.2	0.9	1.6	3.9	6.4	12.0	3.0
4. Tugnuisk coal							
19.3	51.32	3.26	8.1	13.95	4.37	1.0	4.5
5. Ecibastus coal							
45.0	42.6	2.33	1.61	3.56	1.25	0.5	3.15

Table 3. Regime parameters of calculations and experiments.

Coal	Consumption, kg/h				P_{arc}
	Coal G_{coal}	Vapour G_{vap}	Nitrogen G_N	Oxidizer G_O	
1. Kansko-Achinsk	5.8	3.9	1.5	-	80.
2. Turgay	7.36	3.2	1.5	-	61.5
3. Podmoskovnyi	7.18	2.0	1.5	-	61.5
4. Tugnuisk	2000	-	3950	1050	101.6
5. Ecibastus	1600	-	3160	840	150.

Here we can see the results of calculations of Turgay coal vapour gasification (the 2-nd coal in the tables).

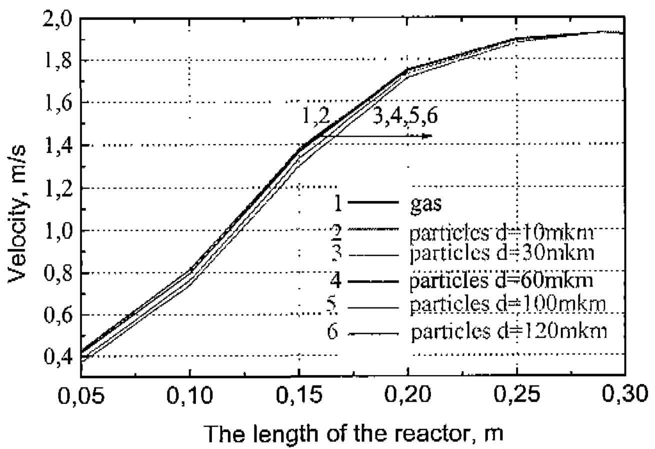

Fig. 1. Turgay coal particles and gas velocity change along the plasma reactor.

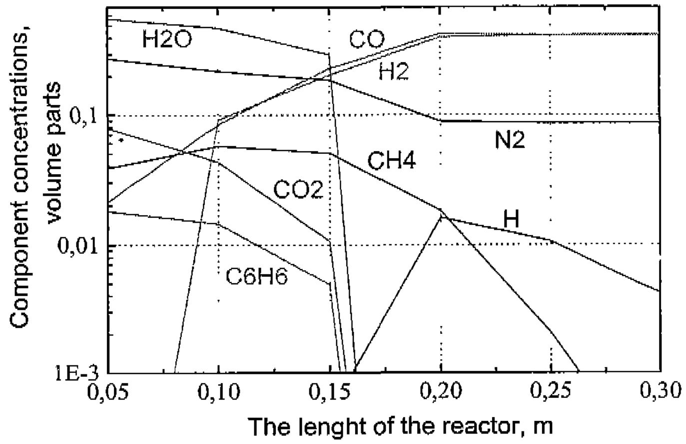

Fig. 2. Turgay coal gasification products concentrations change along the plasma reactor.

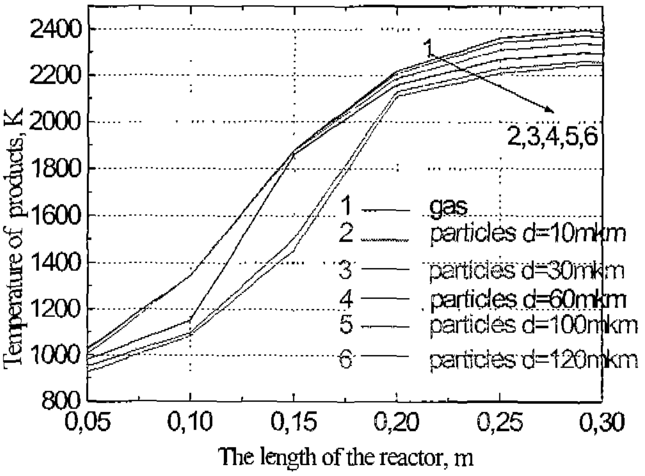

Fig. 3. Turgay coal particles and gas temperature change along the plasma reactor.

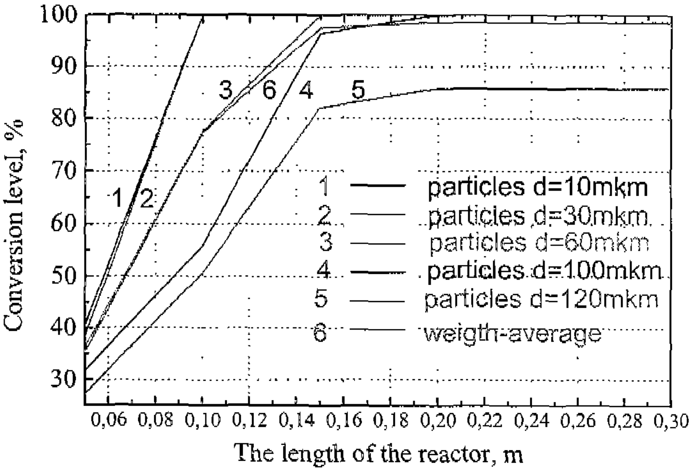

Fig. 4.Turgay coal particles conversion level change along the plasma reactor.

3. EXPERIMENT

Experiments were carried out with the coals above on the experimental plant for plasma conversion of coals. It is shown in the figure 5. It consists of three-phase plasma generator-reactor 1, slag catcher 2, synthesis gas and slag separator chamber 3 synthesis-gas oxidation and cooling chambers 4,5,6, coal pulverisation and feeding system 8, steam feeding system 9. Power of plasmatron, chemical composition of the gas, temperature of all components of the unit, coal, steam and synthesis gas consumption was measured. Also material and heat balances were done.

Comparisons of computations and experiments results for the steam coal gasification are given in the table 4.

Comparison of the experimentally obtained data and calculation results shows a satisfactory agreement between them and confirms the possibility of predicting the parameters essential for practice: reaction zone length, synthesis gas yield, the mixture composition and others.

The calculations also give useful information on some characteristics of the processes that are difficult to obtain experimentally, in particular the velocities, temperatures, and degrees of carbon conversion of different size coal particles.

The processes of vapour gasification of various coals in the plasma reactor has been studied.

Table 4. Comparison between experimental and calculated data.

Coal	Method	T, K	Content, vol.%		X_c, %
			CO	H_2	
Kansko-Achinsk	Experiment	3000	39.6	45.1	95
	Calculation	3224	39.1	41.6	92.7
Turgay	Experiment	3100	35.8	49.4	92.3
	Calculation	2765	39.9	44.9	86.6
Podmoskovnyi	Experiment	3000	38.2	47.5	90.5
	Calculation	2754	32.0	48.0	85.5

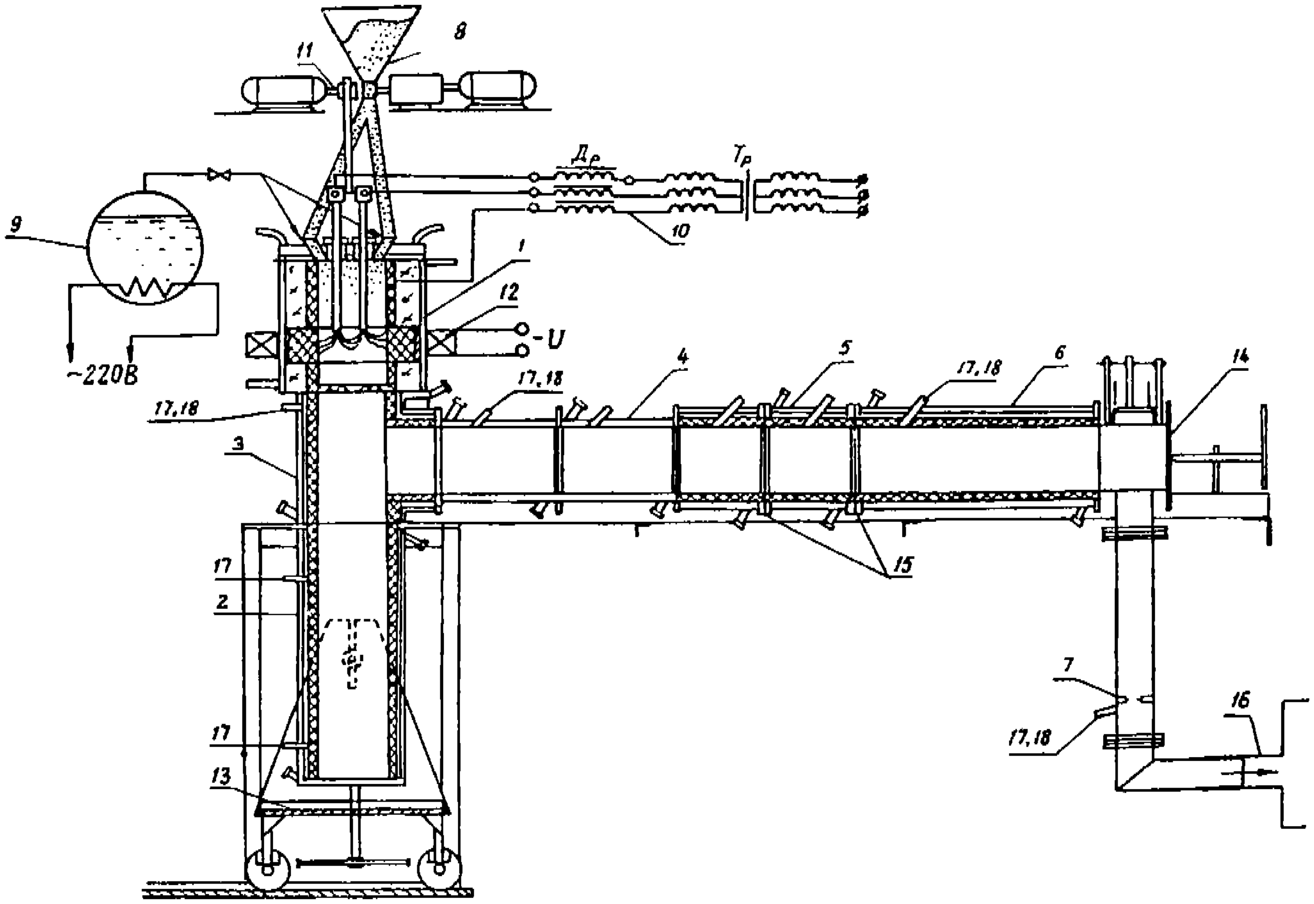

Fig. 5. Experimental apparatus for the plasma conversion of coals.

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