ELECTRON-BEAM SYSTEMS FOR REALIZATION OF PLASMA TECHNOLOGIES

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Abstract

Electron beam (EB) system for initiation of plasma chemical reactions are considered in this paper for a series of technologies. Application of these systems is possible in such technologies as electron-beam cleaning of exhaust gases of toxic impurities (nitric oxides), conversion of silicon tetrachloride ($SiCl_4$) into trichlorosilane ($SiHCl_3$), deposition of silicon films. The main advantages of electron-beam plasma generation in this case are decreasing of power inputs and increasing of velocity of plasma chemical processes.

The electron beam system designed for conversion of $SiCl_4$ into $SiHCl_3$ is described. The power of electron beam mounts to 20 kW, accelerating voltage – 100 kV, design productivity of the system – up to 10 g/s.

The small-size test electron-beam facility using for the purification of exhaust gases is represented. The main parameters of facility are: accelerating voltage – 80…100 kV, beam current – 0…20 mA, gas output capacity – 0…50 l/s, initial temperature of treated gas – 20…150 ^{o}C; radiation dose – up to 100 kGy. The results of experimental investigations conducted on this system are cited.

ELECTRON-BEAM SYSTEM FOR CONVERSION OF SILICON TETRACHLORIDE INTO TRICHLOROSILANE

The principal objective of the system is the extraction of EB into gas of atmospheric pressure containing $SiCl_4$. The flowchart of the EB system is presented in Fig. 1 its appearance – in Fig. 2.

The primary power supply unit (1) is a frequency converter that converts the standard three-phase supply-line voltage of 380 V, 50 Hz into variable voltage with frequency of 1kHz. In a low-sized transformer-rectifier unit (TRU) (2) the voltage rises up to 100 kV, as well as its rectification and filtration occurs. Thus, the electron gun (3) is supplied with direct voltage. The EB (4) forming occurs in the electron gun (3). The extraction device (5) provides the pressure drop required for system operation. It represents the pumped lock-chambers with the holes of 2-3 mm in diameter through which the electron beam is transported.

The following systems are necessary for successful operation: vacuum system (6) providing required pressure drop, magnetic system (7) obstructing the increase in EB radius and providing its required one in the range of burnable partitions, focusing solenoids power supply system (8) and cooling system for solenoids and burnable partitions (9). The cut off system (10) is designed to cut off the extraction device and electron gun from corrosive gas of the operating area.

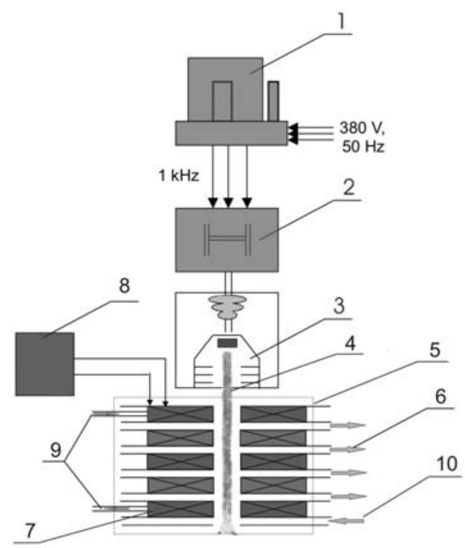

Figure 1: Flowchart of the EB system.

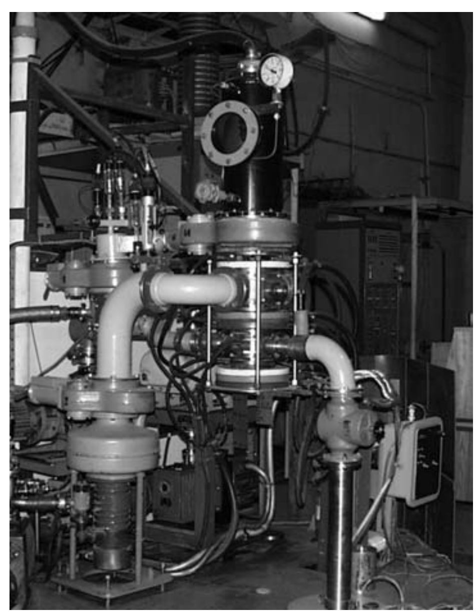

Figure 2: Electron beam system designed for conversion of silicon tetrachloride into trichlorosilane.

The system was developed, manufactured and assembled. The main facility parameters are: power – 20 kW, accelerating voltage – 100 kV, design productivity – 10 g/s. At the moment the experimental work on this system is carried out.

ELECTRON-BEAM SYSTEM FOR GAS CLEANING

The Experimental Facility

A facility on the basis of small-sized accelerator with extraction of the concentrated EB into the atmosphere have been developed for carrying out investigations on exhaust gases cleaning of gaseous toxic impurities. The main facility parameters: accelerating voltage - 80..100 keV, beam current – 0..20 mA, gas flow rate – 0..50 l/s, an initial temperature of gas treated – 20..150 ^{o}C, radiation dose – up to 100 kGy.

The facility flowchart is presented in Fig. 3, its appearance – in Fig. 4.

The facility includes the following key units: gas heating unit with gas mixture preparation unit 1; radiation-chemical reactor 2; beam plasma generator 3; gas withdrawal system 4 and ventilation system 5.

The gas-heating unit with the gas mixture preparation unit is intended for simulation of gas ejected by industrial chimney. Here gas heating is implemented up to the required temperature and insertion of pollutants and all necessary reagents is happened.

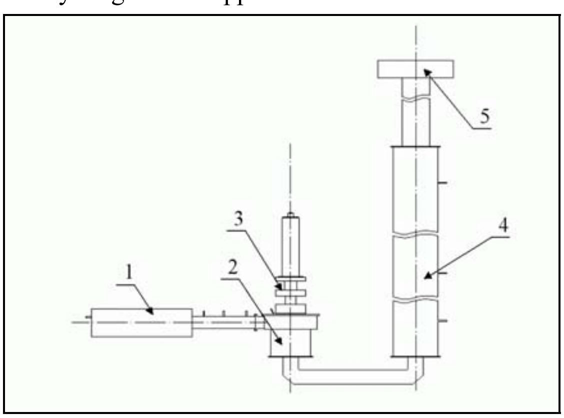

Figure 3: Flowchart of facility for EB gas cleaning.

The radiation-chemical reactor is a stainless steel tank where gas treatment via electron-beam plasma occurs. The active radicals generating under the influence of fast-moving electrons stimulate the passing of a number of chemical reactions resulting in binding of impurities.

The beam plasma generator is a device designed for forming and acceleration of the concentrated EB with subsequent extraction into dense gas through the differential pumping system. It was developed on the basis of updated facility for extraction of steady concentrated EB into gas of atmospheric pressure [1].

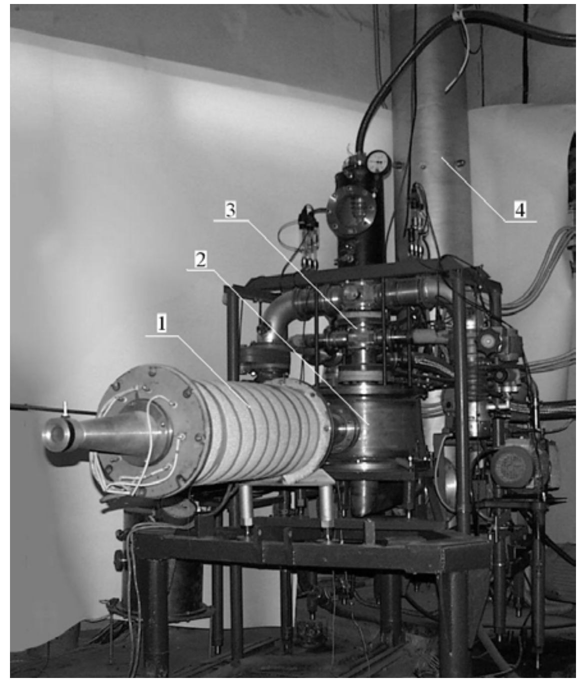

Figure 4: Experimental facility for gas cleaning of toxic impurities with the help of concentrated electron beam.

The gas withdrawal system is a heat-insulated pipe of 400 mm in diameter and length of 4 m. It is the largest part of the facility. Its major purpose is gases keeping inside the system up to the moment of completion of the principal chemical reactions. The proper simulation of the processes, occurred in any real chimney, requires uniform gas temperature inside the whole system. For that purpose all withdrawal system is equipped with thermal insulation.

The ventilation system is intended for gas pumping through the pipeline. Its principal unit is air-exhauster, a connection circuit of which eliminates an opportunity of gas escape from the pipeline.

The measured parameters of the facility are gas flow rate, gas temperature, the EB parameters, reagents' flow and also gas composition before and after treatment.

Gas flow rate is measured by means of a normal Venture tube. The flow rate metering error does not exceed 5 %.

Gas temperature is taken in several points (an ambient temperature, at an outlet and at inlet of radiation-chemical reactor. The measurements are taken with the help of the semi-conducting temperature sensors.

The EB parameters (accelerating voltage and current) are measured via the facility metering devices, gas composition and humidity are determined by a gas-analyser TESTO-350. The gas-analyser allows measuring the concentration of the following substances: NO — 0..3000 ppm; NO_2 — 0..500 ppm; SO_2 — 0..5000 ppm, as well as gas temperature and humidity.

Table 1. The results of the investigations.

Experiment #	Radiation dose, kGy	Concentration of water vapour added, cm^{-3}	NO concentration, cm^{-3}	NO_2 concentration, cm^{-3}	Cleaning efficiency, %
An initial state	0	0	$4{,}3\cdot10^{14}$	$4{,}3\cdot10^{14}$	–
1	10	0	Δ^*	$3{,}8\cdot10^{14}$	56
2	3,0	$1{,}4\cdot10^{15}$	Δ^*	$2{,}9\cdot10^{14}$	66
3	10	$1{,}4\cdot10^{15}$	Δ^*	$2\cdot10^{14}$	77

*- Here symbol Δ denotes that the concentration is lower than a threshold of device sensitivity equal to 10^{13} cm^{-3}

The reagents' flow, supplied to the gas pipeline, is taken depending on pressure and gas temperature in front of the flow controller washer.

Radiation dose is determined by difference in gas temperature at the outlet and inlet of the reactor.

The Experimental Results

The facility passed preliminary tests on gas stream cleaning from nitric oxides. The preparation of toxic impurities was carried out by thermal decomposition of nitric tetroxides into NO and NO_2. The mixture obtained consisted of NO and NO_2 in 1:1 ratio.

Water supplied to the gas preparation unit as vapour. Water vapour availability is rather noticeable factor influencing on a degree of nitric oxides removal as the most chemically active radicals OH and H are namely generated from water molecules under the effect of fast electrons. Besides, water needs for dissolution of the higher oxides NO_2 with acid generation. Acid in turn is well neutralised by various reagents such as NH_3, NH_4OH, or KOH with generation of easily removing solid salts that may be used as mineral fertilisers.

The initial concentrations of NO and NO_2 was $4{,}3\cdot10^{14}$ cm^{-3}. The essence of an electron irradiation is NO conversion, which is extremely poor dissolved in water, into NO_2. The direct influence of the fast electrons on NO_2 is feebly. The results of the investigations are shown in table 1.

From the data obtained follows that at radiation dose of 10 kGy an efficient conversion of NO into NO_2 takes place (experiment #1). At that, NO_2 dissolves partially in residual water vapour, always containing in air. At the purposeful addition of water in gas stream (experiment #3) NO_2 concentration reduces significantly. It possible to obtain fine cleaning efficiency (66 % - experiment #2) at relatively small power consumption (3,0 kGy).

CONCLUSION

The electron beam system has been designed for conversion of $SiCl_4$ into $SiHCl_3$. It was assembled and successfully tested. The main parameters of the system are: power – 20 kW, accelerating voltage – 100 kV, beam current up to 200 ma.

The small-size test electron-beam facility using for the purification of exhaust gases has been constructed. The main parameters of facility are: accelerating voltage – 80…100 kV, beam current – 0…20 mA, gas output capacity – 0…50 l/s, initial temperature of treated gas – 20…150 ^oC; radiation dose – up to 100 kGy.

The experimental results of gas EB cleaning of toxic impurities (nitric oxides NO_X) have been presented. It has been shown that at the initial NO_X concentrations at a level of 10^{15} cm^{-3} the cleaning efficiency reaches 60-80 % at radiation doses in the range of 3 - 10 kGy depending on gas humidity.

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REFERENCES

[1] O.A. Gorshkov, A.A. Ilyin, A.S. Lovtsov, R.N. Rizakhanov "The Facility for Extraction of Concentrated Electron-beam into Gases of the Atmospheric Pressure." Instruments and Experimental Techniques, 2002, pp. 163-164. (in Russian).