ABSTRACT

Theses for the degree of Doctor of Philosophy (PhD) in specialty
6D072300 - "Technical Physics"

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Plasma gasification of municipal solid waste (MSW)

General description of work

This dissertation is devoted to the method of plasma gasification of municipal solid waste (MSW). For conducting numerical studies, TERRA and Plasma-Waste thermodynamic and kinetic calculation software packages were used, and a bench installation for plasma gasification of solid waste was developed for experimental studies.

Relevance of the research topic

The quality of human life is a very important criterion for the development of society and civilization. After the start of industrialization and the steady growth of cities and large settlements, the accumulation of waste in them led to a rapid deterioration of the environment and the overall quality of urban life. Sanitary cleaning of cities and cleaning territories from waste is a necessary process that affects the quality of life of the population.

In turn, the degree of influence on the cleanliness of the air basin, water bodies, soil and the level of the general sanitary and epidemiological situation, the problem of waste disposal has a significant impact on the comfort of life. In the past, technologies for the destruction of waste through incineration and disposal at special landfills completely coped with the mission assigned to them; now, due to the increase in the amount of waste and its diversity, disposal in the above ways can pose a serious threat to the environment. That is why today the relevance of developing new, efficient and environmentally friendly disposal methods is more acute than ever.

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Waste management in Kazakhstan, including accounting for education, collection, use, disposal and disposal of solid waste has become a big social problem in recent decades, which has the most important sanitary and hygienic aspect. One of the priorities in Kazakhstan is the further development of the country's resource potential through an increase in the share of renewable energy, the transition to green technologies, modern utilization and processing of solid waste.

To date, the share of processed and utilized solid waste is 5%, and only 69% of the country's population are provided with waste collection and disposal services. In

turn, the proportion of landfills that meet environmental requirements and sanitary standards is 16%. By 2030, it is planned to cover 100% of the population in garbage collection, and 95% of landfills will have to comply with international sanitary standards, while the share of waste processing will need to be increased to 40% in 2030 and to 50% in 2050.

At present, in Kazakhstan, solid waste landfills, with the exception of the metropolitan area, do not meet international standards. I also note the ban on the burial of plastic, polyethylene, paper and cardboard that came into force in January 2019. Thus, the creation of an alternative infrastructure and the development of modern technologies for environmentally sound processing of solid waste becomes especially relevant.

The connection of the topic of the dissertation with the plans of scientific work

Experimental studies of plasma gasification of solid waste were carried out on a facility designed and built as part of research work on targeted funding of the Committee of Science, the Ministry of Education and Science of the Republic of Kazakhstan on the priority "Energy and Engineering" BR05236507 "Energy technologies for the efficient processing of solid and liquid industrial and household waste , including toxic, with the production of fuel gas and inert mineral material ", as well as under the grant project I Research Committee of Science, Ministry of Education and Science of the Republic of Kazakhstan 3078/GF4 'plasma technology for the production of energy synthesis gas from carbon-containing waste"

Purpose of the study

The purpose of the dissertation research is to develop a modern, effective and environmentally friendly technology for plasma gasification of solid waste and conduct numerical and experimental studies of gasification of solid waste on the developed plasma installation. To achieve this goal it is necessary to solve the following tasks:

– Perform a literature review of the methods of processing solid waste and determine the most effective technology for their disposal

– Perform thermodynamic analysis of plasma gasification of solid waste with various gasification agents

– Perform kinetic modeling of plasma gasification of solid waste and determine the geometric parameters of the plasma reactor

– Perform experimental studies of plasma gasification of solid waste

– Compare the results of experimental studies with the results of thermodynamic and kinetic calculations of plasma gasification of solid waste

Object of study

Technology of plasma gasification of solid waste.

Subject of study

A complex of numerical and experimental studies of plasma gasification of solid waste.

Research methods

Numerical methods using software systems for thermodynamic calculations TERRA and kinetic calculations Plasma-Waste. Experimental studies using the

installation for plasma gasification of solid waste. Balance methods of numerical and experimental studies of plasma gasification of solid waste.

Provisions for protection

– Numerical modeling showed that plasma gasification of solid waste allows obtaining high-calorie combustible gas with a concentration of CO = 31.7–33.6% and H_2 = 50.7–60.9%, depending on the gasification agent used (air or steam), and neutral slag. In this case, the specific heat of combustion of the combustible gas obtained by air gasification is 3410 kcal/kg, and with steam – 4640 kcal/kg.

– The design of the installation for plasma gasification of solid waste with a capacity of 30 kg/h. with a plasma torch with a rated electric power of 70 kW. The plasma reactor is a water-cooled box made of cubic stainless steel, lined with refractory bricks from the inside, with a working volume of 0.091 m^3. MSW is fed into the reactor in the form of briquettes through an inclined pipe on the front wall of the reactor.

– In an experiment on gasification of solid waste in air plasma at a specific energy consumption of 4.5 kWh / kg, a degree of carbon gasification of 91.8% was achieved and combustible gas of the following composition was obtained, vol.%: CO - 26.5, H_2 - 44.6, N_2 - 28.9.

– The optimal parameters of plasma gasification of solid waste are: the average mass temperature in the reactor is 1600 K, the pressure is 0.1 MPa and the mass ratio of solid waste/oxidizer (O_2) is 11.1 kg/kg (solid waste/air – 2.5 kg/kg, solid waste/steam – 10 kg/kg).

Novelty of work

The following new results were obtained in the work:

– Numerical modeling showed the possibility of producing high-calorie combustible gas based on the developed technology for plasma gasification of solid waste.

– A continuous pilot plant for plasma gasification of solid waste has been developed and created.

– At the created facility, experiments were conducted on plasma-air gasification of solid waste and the degree of carbon gasification reached 91.8%.

– The optimal parameters of the process of plasma gasification of solid waste have been determined.

Theoretical and practical significance of the research

The calculated values of the operating parameters of the installation for plasma gasification of solid waste are obtained and the general laws of the processes of plasma gasification of solid waste in various gasifying agents are determined. A continuous pilot plant was created for plasma gasification of solid waste, experiments were carried out, and optimal operating parameters of the process for plasma gasification of solid waste were determined. The results of studies of plasma gasification of solid waste were used in making technical decisions to develop a feasibility study on the optimal organization scheme for the utilization of solid municipal waste in Ulan-Ude, the Republic of Buryatia.

Personal contribution of the author

The personal contribution of the author lies in the fact that the dissertation work, the solution of tasks and numerical calculations are performed by the author

independently. The author took an active part in the creation of a plasma installation and experiments on plasma gasification of solid waste. The objectives of the study, the choice of methods and discussion of the results were carried out jointly with supervisors.

The reliability and validity of the results

In the dissertation, the well-known and tested thermodynamic and kinetic mathematical models of TERRA and Plasma-Waste were used. The reliability and validity of the results are also confirmed by publications in a foreign journal with a non-zero impact factor and in publications recommended by the Committee in the field of education and science of the Ministry of Education and Science of the Republic of Kazakhstan, and in the proceedings of international scientific conferences near and far abroad.

Approbation of a dissertation

The results obtained in the thesis were reported and discussed:

– at the International Scientific Conference "Modern Advances in Physics and Fundamental Physical Education" (2016, Almaty, Kazakhstan)

– at the IX International Symposium "Combustion and Plasma Chemistry" (2017, Almaty, Kazakhstan)

– at the International Conference dedicated to the 100th anniversary of Academician M.F. Zhukova “Gas-discharge plasma and its application” (2017, Novosibirsk, Russia)

– at the Sixteenth International Waste Management and Landfill Symposium International Conference (2017, S. Margherita di Pula, Cagliari, Italy)

– at the international conference «10th International Conference on Plasma Assisted Technologies (ICPAT-11)» (2018, Adu Dhabi, UAE)

– at the VIII International Symposium on Theoretical and Applied Plasma Chemistry (2018, Plyos, Russia)

– at the international conference «17th International waste management and landfill symposium» (2019, S. Margherita di Pula, Cagliari, Italy)

Publications

Based on the materials of the thesis, 14 published works were published: 4 in journals from the KKSON List of the Ministry of Education and Science of the Republic of Kazakhstan to publish the main results of dissertations for the PhD degree and one article in a journal of foreign countries with a non-zero impact factor included in the international information resource SCOPUS. 7 works in collections of international scientific conferences, including 5 in materials of foreign conferences.

Research results

Various technologies for processing solid waste are considered and the most promising technology for plasma gasification of solid waste is selected.

Using the TERRA software package, thermodynamic calculations of plasma-air and plasma-vapor gasification of solid waste in the temperature range 300 – 3000 K. At an optimum temperature of 1600K, the specific energy consumption for air gasification of solid waste is 1.92 kWh/kg, and for steam gasification is 2.44 kWh/kg.

Using the Plasma-Waste program, kinetic calculations of plasma gasification of MSW in air and steam have been performed, and it has been shown that during the

residence time of MSW particles in a plasma reactor (0.4 - 0.7 s), high-calorific synthesis gas with a heat of combustion of about 3540 kcal is formed at the outlet of the reactor / kg, and from 1 kg of MSW 1.16 kg of combustible gas is formed during plasma-air gasification. In plasma-vapor gasification, during the residence time of MSW particles in a plasma reactor (0.7 - 1.2 s), high-calorific syngas with a calorific value of about 5070 kcal / kg is formed at the outlet of the reactor, and 0.87 kg of pure syngas is formed from 1 kg of MSW.

Comparison of the results of thermodynamic and kinetic calculations confirmed the adequacy of the physical and mathematical models used for the numerical analysis of plasma gasification of MSW and the legitimacy of using the TERRA and Plasma-Waste computer programs to determine the geometric parameters of the plasma reactor and the operating conditions of the process of plasma gasification of MSW.

The found parameters and the revealed regularities of the process of plasma gasification of solid waste in various gasification agents were used to develop and create an experimental plasma installation.

A series of studies of plasma-air gasification of solid waste at the experimental setup confirmed the possibility of producing high-calorific synthesis gas, and neutral slag from the mineral mass, consisting mainly of iron carbide, calcium monosilicate, silica, and iron. The specific energy consumption for gasification of solid waste in a plasma reactor according to the results of experiments ranged from 2.25 to 4.5 kW h / kg.

Based on the results of numerical and experimental studies, a modern, efficient and environmentally friendly technology for plasma gasification of solid waste has been developed.

A comparison of the experimental results and the calculations for plasma gasification of solid waste showed satisfactory agreement. Moreover, no harmful impurities were detected in gaseous and condensed products of the process.

Volume and structure of the dissertation

The dissertation consists of introduction, 4 sections, conclusion and list of used sources from 90 items, contains 117 pages of the main computer text, including 42 figures and 3 applications.