8th International Conference on Plasma Assisted Technologies (ICPAT)

18-21 February 2013
Rio de Janeiro , Brazil

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www.plasmacombustion.org

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PLASMA TREATMENT FOR COATINGS AND SURFACE MODIFICATIONS

BUSINESS FORUM

MEETINGS, DISCUSSIONS, NEGOTIATIONS, ENTERTAINMENT

Synopsis

ICPAT-8 will have eleven separate sessions: (1) plasma ignition and flame control; (2) plasma generation, diagnostics, and modeling; (3) fuel reformation and activation; (4) plasma flow dynamics; (5) plasma kinetics; (6) plasma propulsion; (7) new plasma effects and prospective applications; (8) coal, bio-mass, and waste into energy processing; (9) water treatment; (10) plasma treatment for coatings and surface modifications; and (11) business forum. Each section will be followed by a round table session to facilitate discussions on prospective directions of activity and the creation of international research collaborations for joint project development and implementation.

ICPAT-8 is expected to have about 60 oral presentations (30 minutes in duration, including questions and answers), and from 10 to 20 poster presentadions.

ICPAT-8 will pioneer a new form of participation – called an **Informative Message**. This is a way for experts in the various sub-fields of plasma assisted technologies, who, by some reason, can't attend the conference, to still participate in information exchange by submitting an **Informative Message** with information pertaining to their research results or the status of their sub-field. This Message will be presented by an appropriate session chair at the Conference, but will not be included in the Conference Proceedings.

ICPAT-8 will be hosted by the **Brazilian Center for Physics Research (CBPF)** and held February 18 to 22, 2013 in **CBPF: Rua Dr. Xaviera Sigaud, 150. Urca, Rio de Janeiro, RJ. 22290-180. Ph: 55 21 2141-7417, http://www.cbpf.br**.

ICPAT-8 is sponsored by: Applied Plasma Technologies, LLC (APT), USA; International Plasma Technology Center (IPTC), USA; Technological Institute of Aeronautics (ITA), Brazil; University of Paraíba Valley (UniVap), Brazil; Institute of Physics, University of São Paulo, Brazil; Brazilian Center of Physics Research (CBPF), Brazil; São Paulo Research Foundation (FAPESP), Brazil; Technical and Scientific Council (CNPq), Brazil; Brazilian Development Bank (BNDES), Brazil.

During the conference, we plan to honor new members of the International Council of Experts in the field of PAC, announce new international projects and research teams, provide support to junior scientists, and select papers for publication in the *IEEE Transactions on Plasma Science* Special Issue on Plasma-Assisted Combustion. ICPAT-8 proceedings will be available in two formats: a color booklet with abstracts and an after-meeting memory stick. The cost is included in the registration fee.

ICPAT-8 has two new sessions – plasma propulsion and plasma treatment for coatings and surface modifications. This reflects our transition. From the conference presentations and associated discussions, it is clear that many attendees desire that the conference grow into a broader venue that is, expanding the sessions to cover more areas for the application of plasma technologies. ICPAT attendees are prolific idea generators. They see that the same or similar plasma devices that are applied to PAC could be applied in new areas and even with much higher commercial potential and/or faster implementation. So, to that end, we are expanding the coverage of ICPAT to include other plasma technology applications and will do this in future. We realize that there are many plasma conferences held around the world. However, most of those tend to preferentially concentrate on fundamental research and de-emphasize technological applications to a great extent. We wish to be different: ICPAT is meant to include fundamental research, but will emphasize technology, particularly as it applies to commercial applications. We believe that this will distinguish ICPAT from other conferences and provide a unique forum for the 'nuts and bolts' of plasma-assisted R & D, while preserving the core idea of ICPAT – namely an emphasis on the scientific chain from ideas and fundamentals to practical applications.

ICPAT-9 will be held in the U.S.A. in August-September 2014. Please check our web site at http://www.plasmacombustion.com/iwepac.html for further information.

ICPAT – 8

Tentative Agenda

Sunday, 17 February

16.00 – 18.00	Registration: Hall of the Ibiza Copacabana Hotel www.ibizacopacabanahotel.com.br Address: Rua Belford Roxo 250, Rio de Janeiro, Brazil

Monday, 18 February

8.00 – 9.00	Registration: Centro Brasileiro de Pesquisas Físicas (CBPF) Hall of the João Alberto Auditorium
9.00 – 9.30	**ICPAT-8 OPENING** Welcome remarks from: • *Dr. Igor Matveev, Chair,* Applied Plasma Technologies, LLC • *Prof. Homero Santiago Maciel,* University of Paraiba Valley (UNIVAP), Technological Institute of Aeronautics (ITA) • *Dr. Fernando Lázaro F. Júnior,* Pontifical Catholic University of Rio de Janeiro (PUC-Rio), Brazilian Center of Research in Physics (CBPF) Announcements
9.30 – 12.15	**PLASMA IGNITION AND FLAME CONTROL** Chaired by *Prof. Pedro T. Lacava,* Brazil
9.30 – 10.00	**Plasma Fuel Nozzles for Combustion Intensification** *I. Matveev* (Applied Plasma Technologies, LLC; McLean, USA) *S.I. Serbin* (National University of Shipbuilding, Mikolaeiv, Ukraine)
10.00 – 10.30	**Gliding Arc Discharge in Fuel Rich Mixtures of Air and Natural Gas** *J. C. Sagás* (Plasmas & Processes Laboratory – Technological Institute of Aeronautics, S. J. Campos, Brazil) *H. S. Maciel* (NanoTecPlasma Laboratory – IP&D - UNIVAP, S. J. Campos, Brazil) *P. T. Lacava* (Laboratory of Combustion, Propulsion and Energy – Technological Institute of Aeronautics, S. J. Campos, Brazil)

10.30 – 11.00	**Plasma-Assisted Combustion System with High Power Density per Unit Area** *Yu. D. Korolev, O. B. Frants, N. V. Landl, V. G. Geyman, V. S. Kasyanov* (Institute of High Current Electronics, Tomsk, Russia) *Y. Kim, L. A. Rosocha (Los Alamos National Laboratory, Los Alamos, USA)* *I. Matveev (Applied Plasma Technologies, LLC; McLean, USA)*
11.00 – 11.15	Break
11.15 – 11.45	**Low-Current Nonsteady-State Plasmatron in a System for Utilization of the Oil Slimes** *Yu. D. Korolev, O. B. Frants, N. V. Landl, V. G. Geyman, V. S. Kasyanov* (Institute of High Current Electronics, Tomsk, Russia) *A. G. Karengin, A. D. Pobereznikov* (Tomsk Polytechnical University, Tomsk, Russia)
11.45 – 12.15	Round Table on Plasma Ignition and Flame Control
12.15 – 13.15	Lunch
13.15 – 18.00	**PLASMA GENERATION, DIAGNOSTICS, AND MODELING** Chaired by *Dr. Alexei Essipchouk*, Brazil
13.15 – 13.45	**Laser Plasmachemical Method of Investigating Solid Compounds** *O.Yu. Golovchenko* (al-Farabi Kazakh National University, Almaty, Republic of Kazakhstan) *S. Kh. Aknazarov* (Institute of Combustion Problems, Almaty, Republic of Kazakhstan)
13.45 – 14.15	**Study of Behaviour of Plasma Arc for Ignition High Power Plasma Torch in MATLAB/Simulink** *D.G. Lagarejo, H. Riascos* (Universidad Tecnológica de Pereira, Pereira, Colombia)
14.15 – 14.45	**Ion Beam Diagnostic Tool for Plasma-Surface Interactions in Plasma Thruster Discharge Regions** *R. M. Sullivan, A. Pang, M. Martinez-Sanchez, D. G. Whyte* (Massachusetts Institute of Technology, Cambridge, USA)
14.45 – 15.15	**Atmospheric Plasma Discharges for Sterilization Studies** *J. H.C. Souza* (National Health Surveillance Agency, Brasilia, Brazil) *J. L. Ferreira* (University of Brasilia, Brasilia, Brazil)
15.15 – 15.30	Break

15.30 – 16.00	**Formation of Different Core-Corona Structures in the Discharge Channel During the Wire Explosion** *Tkachenko S. I.* (Moscow Institute of Physics and Technology, Dolgoprudny, Moscow Region; Joint Institute for High Temperatures, RAS, Moscow, Russia) *Zhakhovsky V. V.* (Department of Physics, University of South Florida, Tampa, USA; Joint Institute for High Temperatures, RAS, Moscow, Russia) *Shelkovenko T. A., Pikuz S. A.* (Lebedev Physical Institute RAS, Moscow, Russia)
16.00 – 16.30	**Water Steam Plasma Equipment** *L. Charakhovski, A. Marquesi, C. Otani, G. Petraconi R. Bicudo, A.S. da Silva Sobrinho, M.Massi, A. Gorbunov, A. Halinouski* (Istituto Tecnológico de Aeronáutica (ITA), S. José dos Campos, Brazil) *H.S. Maciel* (Instituto de Pesquisa e Desenvolvimento – IP&D/UNIVAP, S. José dos Campos, Brazil)
16.30 – 17.00	**Approximation of Thermal and Electrophysical Properties of Steam and Other Thermal Plasmas for Calculation of Electric Arc on the Anisotropic Model and Physical Modeling of Plasma Arc Torches for Waste Gasification Reactors** *A. F. Bublievsky* (Luikov Heat and Mass Transfer Institute, Minsk, Belarus) *A. V. Gorbunov, A.R. Marquesi, G. Petraconi Filho, C. Otani* (Technological Institute of Aeronautics (ITA), Sao Jose dos Campos, Brazil) *D.A. Bublievsky* (Federal University of Espirito Santo, Vitória, Brazil) *H. S. Maciel* (Institute for Research and Development – IP&D/UNIVAP, São José dos Campos, Brazil)
17.00 – 17.30	**Some Results of Development and Experimental Investigations of High Power and High Pressure RF Torches with Reverse Vortex Plasma Stabilization** *I. Matveev, S. Matveyeva* (Applied Plasma Technologies, LLC; McLean, USA)
13.15 – 18.00	**Multichannel Analyzers of Emission Spectra MAES (POSTER)** *V.A. Labusov, D.O. Selyunin, S.A. Babin* (Institute of Automation and Electrometry, Siberian Branch, Russian Academy of Sciences; VMK-Optoelektronika, Novosibirsk, Russia)

13.15 – 18.00	**Tandem Plasma Torch Development for Thermal Spray Production (POSTER)** *R. J. Silva, H. S. Maciel* (Laboratory of Plasmas and Processes, Department of Physics, Technological Institute of Aeronautics; Institute of Research and Development, University of Vale of Paraíba, São José dos Campos, Brazil) *L.I. Charakhovski, M. P. Gomes, F. P. Pereira, C. Otani,G. P. Filho* (Laboratory of Plasmas and Processes, Department of Physics, Technological Institute of Aeronautics, São José dos Campos, Brazil)
17.30 – 18.00	Round Table on Plasma Generation, Diagnostics, and Modeling
19.00	Welcome Party at CBPF restaurant

Tuesday, 19 February

8.30 – 10.15	**FUEL REFORMATION AND ACTIVATION** Chaired by *Prof. Sergey Serbin*, Ukraine
8.30 – 8.55	**High Power Combined Plasma Chemical Gasification and Combustion System for Contaminated Liquid Hydrocarbons Destruction** *Igor Matveev, S. Matveyeva (Applied Plasma Technologies, LLC; McLean, USA)* *Serhiy Serbin, Vladimir Vilkul, Serhiy Vilkul* (National University of Shipbuilding, Mikolayiv, Ukraine)
8.55 – 9.20	**Preliminary Study on Reformation of Gasification Gas Using Plasma Torch** *Renato C. Neves, João P. Vissotto, Alexandre W. Mazzonetto, Caio G. Sánchez* (Department of Thermal and Fluids Engineering, School of Mechanical Engineering, State University of Campinas - UNICAMP, Brazil)
9.20 – 9.45	**Hydrocarbon Reforming in CO_2 Thermal Plasma** *A.M. Essiptchouk* (Instituto Tecnológico de Aeronáutica - ITA, São José dos Campos, Brasil)
8.30 – 10.15	**Study of Syngas Production from Tar Reforming by Microwave Plasma Torch at Atmospheric Pressure (POSTER)** *L.S. Justiniano, H.S. Medeiros, R.M. Eliott, G. Petraconi, P.T. Lacava, A.S. da Silva Sobrinho* (Technological Institute of Aeronautics, S. J. dos Campos, Brazil) *H.S. Maciel* (IP&D, University of Vale do Paraíba, S. J. dos Campos, Brazil) *M. F. M. Nogueira* (Federal University of Para, Belém, Brazil)
9.45 – 10.15	Round Table on Fuel Reformation and Activation
10.15 – 10.30	Break

10.30 – 11.20	**PLASMA FLOW DYNAMICS** Chaired by *Dr. Leonid I Charakhovski*, Belarus
10.30 – 10.55	**Particle Trapped Vortex Reactor with Meridional Counter Flow Gas Dynamics for Plasma Assisted and Combustion Processes** *A.A. Borissov* (General Vortex Energy Inc., Houston, USA)
10.30 – 11.20	**Comparison Between Global and 2-D Fluid Model Results of a Low Pressure Inductively Coupled Oxygen Plasma (POSTER)** *A. C. Fraile Júnior, D. A. Toneli , M. Roberto* (Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil) *R. S. Pessoa* (Universidade do Vale do Paraíba; Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil)
10.55 – 11.25	Round Table on Plasma Flow Dynamics
11.25 – 16.05	**PLASMA KINETICS** Chaired by *Prof. Vladimir Bychkov*, Russia
11.25 – 11.50	**Electron Energy Distribution Function Control in Inhomogeneous Non-stationary Plasma for Practical Applications** *Anatoly A. Kudryavtsev, Lev D. Tsendin* (St. Petersburg State University, Russia) *Vladimir Bychkov* (M.V. Lomonosov Moscow State University, Russia)
11.50 – 12.15	**On Kinetics of Pulsed Discharge in Humid Air** *Nikolai V. Ardelyan, Konstantin V. Kosmachevsky* (M.V. Lomonosov Moscow State University, Moscow, Russia) *Vladimir L. Bychkov* (FSUE "Moscow Radiotechnical Institute of Russian Academy of Sciences", Moscow, Russia) *Igor V. Kochetov* (Russian State Research Center, Troitsk Institute for Innovation and Thermonuclear Research (TRINITI), Troitsk, Russia)
12.15 – 13.15	Lunch
13.15 – 13.40	**On Kinetics of Pulsed Discharge in Water Vapor** *Nikolai V. Ardelyan, Konstantin V. Kosmachevsky, D.N. Vaulin* (M.V. Lomonosov Moscow State University, Moscow, Russia) *Vladimir L. Bychkov* (FSUE "Moscow Radiotechnical Institute of Russian Academy of Sciences", Moscow, Russia) *Igor V. Kochetov* (Russian State Research Center, Troitsk Institute for Innovation and Thermonuclear Research (TRINITI), Troitsk, Russia)

13.40 – 14.05	**Plasma Processing of Carbonaceous Raw Material** *Vladimir E. Messerle, Alexander B. Ustimenko Oleg A. Lavrichshev, Eleonora F. Ossadchaya* (Combustion problems Institute, Research Institute of Experimental and Theoretical Physics, NTO Plasmotekhnika, Almaty, Kazakhstan)
14.05 – 14.30	**Double Atmospheric Pressure Cold Plasma Jet Divergence in Air** *Abdel-Aleam H. Mohamed* (Department of Physics, Faculty of Science, Taibah University, Almadinah Almunawwarah, Saudi Arabia) *Jae Koo Leea* (Department of Electronic and Electrical Engineering, Pohang University of Science and Technology, Pohang, S. Korea)
14.30 – 14.55	**To Combustion Nature of Discharge Created Fireballs** *Vladimir L. Bychkov* (FSUE "Moscow Radiotechnical Institute of Russian Academy of Sciences", Moscow, Russia)
14.55 – 15.10	Break
15.10 – 15.35	**Research of Short Atmospheric Pressure DC Glow Micro Discharge in Air** *Anatoly A. Kudryavtsev, Alexander Astaviev, Eugene Demidov* (St. Petersburg State University, St. Petersburg, Russia) *Vladimir Bychkov* (M.V. Lomonosov Moscow State University, Moscow, Russia)
11.25 – 16.05	**Effects of the Secondary Electron Emission Coefficient in Radio Frequency Oxygen Discharge (POSTER)** *André C. Fraille Jr., David Tonelli, Marisa Roberto* (Instituto Tecnológico de Aeronáutica, Departamento de Física, S. José dos Campos, S.Paulo, Brazil) *Rodrigo S. Pessoa* (Universidade do Vale do Paraíba,São José dos Campos, S.Paulo, Brazil)
15.35 – 16.05	Round Table on Plasma Kinetics
16.05 – 18.30	**PLASMA PROPULSION** Chaired by *Prof. J. Leonardo Ferreira, Dr. G.M. Sandonato,* Brazil
16.05 – 16.30	**A General View of Plasma Space Propulsion Physics and Technology** *Eduardo Ahedo* (Plasmas and Space Propulsion Team, Technical University of Madrid, Madrid, Spain)
16.30 – 16.45	Break

16.45 – 17.10	**Challenges on the Development and Performance of the Permanent Magnet Hall Thrusters – PHALL** *José Leonardo Ferreira, Ivan Soares Ferreira, Paolo Gessini, Gabriela Possa, Jean Carlo Santos and Rodrigo Miranda* (Plasma Physics Laboratory University of Brasilia, Brasilia, Brazil)
17.10 – 17.35	**PION5 Performance Study in the Production of Thrust. Conference on Plasma Assisted Technologies (ICPAT)** *G.M. Sandonato, J.A.N. Gonçalves, R.T.Irita* (National Institute for Space Research, São José dos Campos, Brazil) *Paolo Gessini* (University of Brasilia at Gama, UnB Gama, Gama, Brazil)
17.35 – 18.00	**Analysis of the Two-Stage Pulsed Plasma Thruster** *Rodrigo Intini Marques, Fernando de Souza Costa, Gilberto Marrega Sandonato* (INPE – Instituto Nacional de Pesquisas Espaciais, Cachoeira Paulista and São José dos Campos, Brazil) *Paolo Gessini* (UnB – Universidade de Brasília, Gama-DF, Brazil)
16.05 – 18.30	**Possibles Equilibria in Microhollow Cathode Discharges (POSTER)** *Marcelo Pêgo Gomes, Bogos Nubar Sismanoglu* (Laboratory of Optics and Spectroscopy, Department of Physics, Technological Institute of Aeronautics, São José dos Campos, Brazil)
18.00 – 18.30	Round Table on Plasma Propulsion

Wednesday, 20 February

8.30 – 11.00	**NEW PLASMA EFFECTS AND PROSPECTIVE APPLICATIONS** Chaired by *Prof. R.M. Galvao*, Brazil
8.30 – 9.00	**HF Plasma Discharge for Surface Modification of Cellulose-Based Materials** *E. G. Ioanid, M. Totolin* ("Petru Poni" Institute of Macromolecular Chemistry, Iassy Romania) *D. E. Rusu, M. C. Ursescu, A.M. Vlad* (National Complex of Museums "Moldova" Iassy, Romania)
9.00 – 9.30	**Recalcitrance of Sugarcane Bagasse before and after Water Plasma Pretreatment** *F. S. Miranda, F.L.C.Lucas, M.O. Silva* (University of Paraiba Valley (UNIVAP), São José dos Campos, Brazil) *R.S. Pessoa, H.S. Maciel, L.V.Santos* (Technological Institute of Aeronautics (ITA); University of Paraiba Valley (UNIVAP), São José dos Campos, Brazil)

9.30 – 10.00	**The Effect of Pretreatment on Enzymatic Hydrolysis of Sugarcane Bagasse: may plasma overcome the recalcitrance of biomass?** *J.G.C. Pradella, R. Borges, G.J.M. Rocha* (Brazilian Bioethanol Science and Technology Laboratory - CTBE, Campinas, Brazil) *F.S. Miranda, R.S. Pessoa; L.V. Santos* (University of Paraiba Valley (UNIVAP), São José dos Campos, Brazil)
10.00 – 10.30	**New Trends in the Electron-Beam Plasmas. Review of the Newly Developed Devices and Areas of the Electron-Beam Plasmas Application** *Vladimir Bychkov* (M.V. Lomonosov Moscow State University, Moscow, Russia) *Sergey Denisuyk* (Moscow Radiotechnical Institute, Moscow, Russia) *Igor Matveev* (Applied Plasma Technologies, LLC; McLean, USA)
10.30 – 11.00	Round Table on New Plasma Effects and Prospective Applications
11.00 – 11.15	Break
11.15 – 15.45	**COAL, BIO-MASS, AND WASTE INTO ENERGY PROCESSING** Chaired by *Prof. Vladimir Messerle*, Kazakhstan, *Dr. Igor Matveev*, USA
11.15 – 11.45	**Theoretical Investigations of a Multistage Plasma Coal Vortex Gasifier** *Serhiy Serbin, Nataliia Goncharova* (National University of Shipbuilding, Mikolayiv, Ukraine) *Igor Matveev* (Applied Plasma Technologies, McLean, Virginia, USA)
11.45 – 12.15	**Plasma-Fuel Systems for Energy Efficiency of Coal-Fired Thermal Power Plants** *Vladimir E. Messerle and Alexander B. Ustimenko* (Combustion Problems Institute, Research Institute of Experimental and Theoretical Physics, NTO Plasmotekhnika, Almaty, Kazakhstan)
12.15 – 13.15	Lunch
13.15 – 13.45	**Vitrification of Hazardous Fly Ash Resulting from Incineration Plants** *A. L. P. Mattei, A. Gorbunov* (Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brasil) *H. S. Maciel* (Universidade do Vale do Paraíba, São José dos Campos, SP, Brasil) *M.A. de Souza* (Vortex Tecnologia, São José dos Campos, Brasil)

13.45 – 14.15	**Thermochemical Accessment of Gasification Process of Biofuels Industry Wastes with Different Plasma Oxidants** *R. Mourão, A. R. Marquesi, A. V. Gorbunov, G. Petraconi Filho, C. Otani, A. A. Halinouski* (Technological Institute of Aeronautics (ITA), São José dos Campos, Brazil)
14.15 – 14.45	**Thermoplastic Waste Processinginto the Alternative Liquid Fuels** *Borys Tymoshevskyy, Mykhaylo Tkach* (National University of Shipbuilding, Mykolayv, Ukraine)
14.45 – 15.15	**Study of Heat Transfer in DC Transferred and Non-transferred Electric Arc Heaters for Plasma Gasification, Nanocarbons Synthesis and Related Processes** *A. Halinouski, A. Gorbunov, G. Petraconi Filho, C. Otani, L. Charakhovski, A. Marquesi* (Technological Institute of Aeronautics (ITA), São José dos Campos, Brazil) *A. Bublievsky, V. Koval* (Luikov Heat and Mass Transfer Institute (HMTI), Minsk, Belarus) *H. Maciel* (Institute for Research and Development – IP&D/UNIVAP, São José dos Campos, Brazil)
15.15 – 15.45	Round Table on Coal, Bio-Mass, and Waste into Energy Processing
15.45 – 16.00	Break
16.00 – 17.45	**WATER TREATMENT** Chaired by *Dr. Isaiah Blankson*, USA
16.00 – 16.15	**Informative Message, ICPAT-8. Water Treatment by Plasmas – Advanced Oxidation/Reduction Technologies (AO/RTs)** *L. A. Rosocha* (Applied Physics Consulting, LLC, Los Alamos, USA) *W. L. Morgan* (Kinema Research and Software, Inc., Monument, USA)
16.15 – 16.45	**Perspectives on the Interaction of Plasmas with Liquid Water for Water Purification** *Isaiah M. Blankson* (NASA Glenn Research Center, Research and Technology directorate, Cleveland, USA) *John E. Foster* (Department of Nuclear Engineering and Radiological Sciences University of Michigan, Ann Arbor, USA)
16.45 – 17.15	**Water Purification by High-Voltage Nanosecond Plasma: Further Experimental Results** *Isaiah M. Blankson* (NASA Glenn Research Center, Research and Technology directorate, Cleveland, USA) *John E. Foster* (Department of Nuclear Engineering and Radiological Sciences University of Michigan, Ann Arbor, USA)
17.15 – 17.45	Round Table on Water Treatment

8.30 – 14.15

PLASMA TREATMENT FOR COATINGS AND SURFACE MODIFICATIONS

Chaired by *Dr. Rajan Bamola*, USA

8.30 – 9.00

Adherence Study of Hydrogenated Amorphous Carbon Film via Optic Sclerometry

F.L.C.Lucas, M.O. Silva, F. S. Miranda (University of Paraiba Valley (UNIVAP), São José dos Campos, Brazil)

Santos, L.C.D (Technological Institute of Aeronautics (ITA), São José dos Campos, Brazil)

R.S. Pessoa, H.S. Maciel, L.V.Santos (University of Paraiba Valley (UNIVAP); Technological Institute of Aeronautics (ITA), São José dos Campos, Brazil)

9.00 – 9.30

Plasma Treatments for Metallic Surface Modification to Obtain Highly Adherent Diamond-like Carbon Coatings

G. Capote (National University of Colombia, Bogota D.C., Colombia)

V. J. Trava-Airoldi and E. J. Corat (Institute for Space Research, Sao Jose dos Campos, Brazil)

L. F. Bonetti (Clorovale Diamantes Industria e Comercio S.A., Sao Jose dos Campos, Brazil)

9.30 – 10.00

Plasma Surface Treatment of Carbon-based Coatings for Superlubricity and Ultra-low Wear

A. Erdemir, O. Eryilmaz (Argonne National Laboratory, Argonne, USA)

10.00 – 10.30

Improved Corrosion Resistance of Multilayer DLC/AlN/Si Structures Exposed to Non-thermalized Plasmas

K. G. Grigorov, D.Teodosiev (Space Research and Technology Institute, Sofia, Bulgaria)

M.Massi (Federal University of São Paulo - ICT, São José dos Campos, Brazil)

H. Homero (UNIVAP - Universidade do Vale do Paraíba, São José dos Campos, Brasil)

B.N. Sismanoglu, J. Libardi (Technological Institute of Aeronautics, Plasmas and Processes Laboratory, São José dos Campos, Brazil)

10.30 – 11.00

Increasing the Surface Energy of TiO_2 Thin Films with Incorporation of Nitrogen Atoms in the Film Lattice

D.A. Duarte, D.R. Irala, M. Massi, H.S. Maciel, A.S. da Silva Sobrinho (Technological Institute of Aeronautics, S. J. Campos, Brazil)

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11.00 – 11.15	Break
11.15 – 11.45	**Plasma Electrolytic Oxidation: Surface Modification for valve alloys** *Rajan Bamola, Paul Robinson and Vasu Srinivasan* (Surface Modification Systems Inc., USA)
11.45 – 12.15	**Wear behavior and chemical processes that control the lifetime of electromagnetic railguns** *I.L. Singer* (SingerTriboscience, Alexandria, (retired from Naval Research Lab, Washington DC), USA)
12.15– 12.45	**Macroscopic Tribocharge Patterns Formed by Polymer Ion Self-arraying on Insulating Polymer Surfaces** *Thiago A. L. Burgo, Fernando Galembeck* (University of Campinas, Campinas, Brazil)
8.30 – 14.15	**PLASMA TREATMENT FOR COATINGS AND SURFACE MODIFICATIONS - POSTER SESSION**
	Study of the Titanium Surfaces Modified by Plasma Immersion Ion Implantation and Deposition (POSTER) *Rita de Cássia C. Rangel, Thalita Benetello, Elidiane C. Rangel, Nilson C. Cruz* (Technological Plasma Laboratory, Paulista State University (UNESP), Sorocaba, Brazil) *Maria Eliziane P. Souza* (Departamento of Chemical and Statistical Engineering, Federal University of São João del Rei, Alto de Paraopeba, Brazil) *Célia Marina A. Freire* (Department of Materials Engineering, University of Campinas (UNICAMP), Campinas, Brazil) *Eliana Aparecida R. Duek* (Biomaterials Laboratory, Medical and Biological Sciences Center, Pontifical Catholic University (PUC), Sorocaba, Brazil) *Wido H. Schreiner* (Department of Physics, Federal University of Paraná, Curitiba, Brazil)
	TiO_2 Films Deposited by Grid-Assisted Magnetron-Sputtering (POSTER) *D. R. Irala* (Centro Universitário Católica de Santa Catarina - Campus Joinville, Brazil) *Maciel H.S, Duarte D.A.* (Technological Institute of Aeronautics, Plasmas and Processes Laboratory, S. J. Campos, Brazil) *Recco, A.A.C., Fontana, L.C.* (Santa Catarina State University, Plasmas Physics Laboratory, Campus Universitário, Joinville, Brazil)

	Deposition of Diamond-Like Carbon films by High Power Impulse Magnetron Sputtering – HiPIMS (POSTER) *S. F. Fissmer, J. C. Sagás* (Technological Institute of Aeronautics (ITA-CTA), São José dos Campos, Brazil) *M.Massi* (Federal University of São Paulo – ICT; Technological Institute of Aeronautics (ITA-CTA), São José dos Campos, Brazil) *L. V. Santos* (University of Paraíba Valley (UNIVAP); Technological Institute of Aeronautics (ITA-CTA), São José dos Campos, Brazil)
	A Global Model Coupled with Langmuir Adsorption Kinetics Applied for Investigation of Inductively Coupled CF4 Plasma Etching of Silicon (POSTER) *D. A. Toneli, A. C. Fraile Júnior, M. Roberto, G. Petraconi* (Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil) *R. S. Pessoa, H. S. Maciel* (Universidade do Vale do Paraíba; Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil)
	Temperature Studies on DLC Film Growth for Space Applications (POSTER) *L. L Ferreira, A. S. da Silva Sobrinho, P. A. Radi, S. F. Fissmer* (Technological Institute of Aeronautics - ITA, São José dos Campos, Brazil) *L. V. Santos* (University Vale of Paraíba - UNIVAP, São José dos Campos, Brazil) *M. Massi* (Federal University of São Paulo - UNIFESP, São José dos Campos, Brazil)
	Afterglow Microwave Plasma Surface Treatment of EPDM Rubber for Aerospace Application (POSTER) *F. P. Pereira, J. V. da Maia, A. S. da Silva Sobrinho* (Laboratory of Plasmas and Processes, Technological Institute of Aeronautics, São José dos Campos, Brazil) *M. Massi* (Federal University of São Paulo, São José Campos, Brazil) *S. A. C. Mello, J. C. N. Dutra* (EBO, Chemistry Division, IAE, CTA, São José dos Campos, Brazil)
12.45 – 13.45	Lunch
13.45 – 14.15	Round Table on Plasma Treatment for Coatings and Surface Modifications

14.15 – 15.45	**BUSINESS FORUM** Chaired by *Dr. Igor Matveev*, USA *Dr. Vladimir Airoldi*, Brazil
14.15 – 14.45	**Combined Cycle Gas Turbine Power Plant with Integrated Plasma Coal Gasification** *Igor Matveev* (Applied Plasma Technologies, LLC; McLean, USA) *Nikolay Washclilenko, Serhiy Serbin, Nataliia Goncharova* (National University of Shipbuilding, Mikolayiv, Ukraine)
14.45 – 15.15	**Parametric Analysis of Using Thermal Plasma Produced Syngas from Coal for the Engine Combustion Enhancement and for Iron Ore Direct Reduction** *A. V. Gorbunov, G. Petraconi Filho, C. Otani, P.T. Lacava, A.A. Halinouski* (Technological Institute of Aeronautics (ITA), Sao Jose dos Campos, Brazil) *A.Y. Pilatau, H.A. Viarshina* (Belarusian National Technical University, Minsk, Belarus) *O.S. Nozhenko, V.Y. Baranov* (Volodymyr Dahl East-Ukrainian National University, Lugansk, Ukraine) *D. Jasinski* (Warsaw University of Technology, Warsaw, Poland) *H. S. Maciel* (Institute for Research and Development – IP&D/UNIVAP, São José dos Campos, Brazil)
15.15 – 15.45	**Economics on Application of the RF/IC Plasma Systems** *Igor Matveev* (Applied Plasma Technologies, LLC; McLean, USA)
15.45 – 16.15	**Technology for Tire's Waste Processing into the Alternative Liquid Fuels** *Borys Tymoshevskyy, Mykhaylo Tkach* (National University of Shipbuilding, Mykolayv, Ukraine)
16.15 – 18.00	**MEETINGS, DISCUSSIONS, NEGOTIATIONS, ENTERTAINMENT**

CONFERENCE CLOSING

Plasma Fuel Nozzles for Combustion Intensification

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Contemporary power plants are characterizes by a wide range of turn down ratio. Therefore, under some operating conditions the working process in a combustor is far away from the optimal one. Among existing means of the combustion intensification, the plasma-chemical method [1]-[2] based on interaction between the low-temperature plasma jet generated by a plasma source and fuel, promises the greatest potential. As a result of thermal, kinetic, and turbulent interaction of a plasma-fuel jet, having a specific composition, temperature, and concentration of the active species, the main fuel oxidation reactions in a combustor are enhanced, resulting in reduced toxicity of the exhaust gases and significant improvements of the combustion process efficiency and stability.

Interaction of the air plasma and fuel can be organized in a special device named plasma fuel nozzle (PFN) which consists of a miniature plasma torch and a fuel atomizer [2].

Recent progress in development of the non-thermal plasma torches with non steady-state gas discharge gave a new life to the PFN concept. Advantages of non-thermal plasma as higher stability, longer lifetime, lower arc temperature, lower averaged power consumption due to nature of the non steady-state discharge, opportunity of direct fuel injection into the arc chamber, wider operation pressure and flow range, and unique portable design allowed renew efforts on the PFN development for power generation and propulsion.

As a result of numerous tests mainly with different fuels and analyzes of prospective atomizing schemes, a new type of atomizer with overlapping crossed swirling flows named cross-flow nozzle was suggested [3].

Our preliminary CFD calculations show promising possibilities to ensure the effectiveness of mixing various components, including liquid and gaseous fuels, air and steam, before their injection into a combustor, which is then expected to further improve efficiency and performance. Figure 1 shows the 3D-geometry and contours of velocity magnitude in the cross-flow fuel nozzle volume. Note, that plasma feedstock air, gaseous methane, and atomizing air are injected into the separate input channels.

New nozzles allow high-quality fuel atomization at low pressures and flows of the atomizing agent (compressed air or steam), ensure fuel uniformity in the outcoming stream, allow a wide turndown ratio, establish a stable fuel cone angle and length, and reduce fuel consumption. It is known, that at fluid flow in the cross-flow channels, the turbulent nature of this flow is realized at Reynolds numbers Re_c = 500-600, that are considerably lower in comparison with Re_c in smooth pipes (≈ 2300). One more feature of such a flow structure is appearance of the cavitation processes in certain cases due to formation of the vortex bundles

inside the cross-flow channels. This phenomenon also promotes improvement of the components mixing.

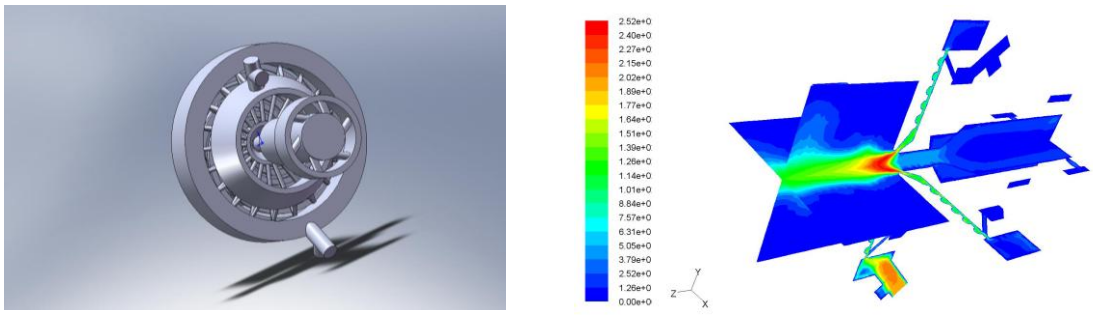


Fig.1. 3D-geometry and contours of velocity magnitude inside the cross-flow fuel nozzle

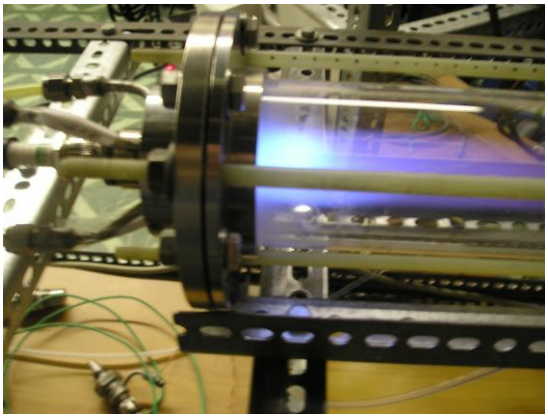
Overview of designed PFN prototypes with cross flow atomizing can be seen in Fig. 2.

Fig.2. PFN modifications with the cross flow channels.

Each PFN modification has three inputs – for plasma gas, fuel, and atomizing agent - optionally air, fuel gas, or water steam. Fuel and atomizing agent mixing occurs in numerous especially shaped crossing points of the fuel and atomizer channels. After proper mixing, fuel mist is uniformly distributed inside a reaction chamber with a plasma plum injection for ignition and partial gasification. So plasma nozzle output consists not just of the atomized fuel droplets, but also active and high speed products of the fuel-rich mixture plasma chemical reactions, which initiate chain branching in the combustion zone. It's obvious that by flows regulation PFN operation could be tuned to ignition and flame control modes.

To compare different fuel injection concepts and their influence on combustion processes the prototype with standard Hago nozzle and the cross flow PFN have been tested on gaseous and diesel fuels within a small-scale atmospheric pressure reverse vortex combustor [4]. Experimental setup was equipped by TESTO-350XL gas analyzer and allowed the emission components measurements as well as all flows, flue gas and combustor walls temperatures. The test results are provided in Fig. 3 and confirmed very low level of NO_x emission.

Designed PFN were tested with plasma gas air, oxygen, air/propane/methane blends, and water steam; such fuels as methane, propane, and diesel; with atomizing media as air, water steam, and fuel gas. The tests have been performed in open air, as in several modifications of the reverse vortex combustor with total air flow by 20 g/s. They showed that developed line of the PFN satisfies major initial requirements, could be further scaled up, and adjusted to a variety of commercial applications, including chemical reactors, gasifiers, special burners, propulsion systems, and prospective gas turbines.



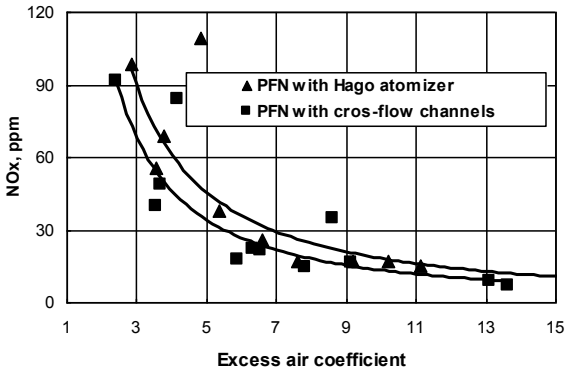


Fig.3. The cross-flow plasma fuel nozzle in operation inside the reverse vortex combustor and dependence of NO_x emission on the air access coefficient

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Gliding Arc Discharge in Fuel Rich Mixtures of Air and Natural Gas

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Gliding arc discharges are an efficient way to generate non-equilibrium atmospheric pressure plasmas, which allows the achievement of a highly reactive medium with high flow rates when compared to corona and dielectric barrier discharges (DBD) [1]. These characteristics make the gliding arc discharges a very interesting tool for applications in plasma assisted combustion [2], for example, in rich-quenching-lean (RQL) combustors. In these systems the combustor is divided into two zones: a first zone with a fuel rich combustion and a second zone for lean combustion [3]. This approach intends to inhibit high temperature, reducing nitric oxide (NO_x) emission and also to minimize instabilities in the lean combustion by the injection of fuel rich combustion radicals, like molecular hydrogen (H_2) and carbon monoxide (CO). For this kind of system, gliding arc discharges can be used in the fuel rich combustion, once that the inflammability limits are increased and the generation of a reactive medium can increase H_2 production. Thus, aiming to understand the physical and chemical processes in plasma assisted combustion, a gliding arc in tornado reactor [4] was built to investigate the characteristics of gliding arc discharge in fuel rich mixtures of air and natural gas.

The experiments were carried out using an AC power supply (60 Hz) in the range of 100 to 400 W. The mass flow rates of air and natural gas were monitored by mass flow meters, while the electrical parameters of the discharge were measured via a digital oscilloscope to verify the behavior of the discharge voltage and current in time and to obtain parameters like the breakdown voltage. To study the chemical processes an optical emission spectrometer (OES) was used to identify radiative transitions of species generated in the discharge and a mass spectrometry (MS) measured the species at the gas exhaust. Measurements with and without plasma were realized.

A flame can be sustained without plasma in a narrow range of equivalence ratio between 0.7 and 1.4, while a stable flame is sustained with plasma at the reactor exit between equivalence ratios from 0.5 to 2.2. For equivalence ratios higher than 1.7, the flame is power dependent, *i.e.* it occurs only with increased power. The plasma also increases the flame intensity as noticed by temperature measurements and by visual inspection (Fig. 1). This increased intensity can be attributed to the electric power injected and also to the burning of H_2 and fragmented hydrocarbons generated in the discharge, as suggested by the OES and MS analysis. The H_2 production by the discharge can be seen in Fig. 2. In fact, it was noticed that the H_2 production decays when a flame is sustained, because the H_2 generated in the

plasma is burned in the flame. Another very interesting result was obtained using a high speed camera (Fig. 3), where it can be noted that the flame front moves in the opposite direction of gas flow and that the discharge and the flame are spatially separated, *i.e* the flame is generated in a gas "treated" by plasma.

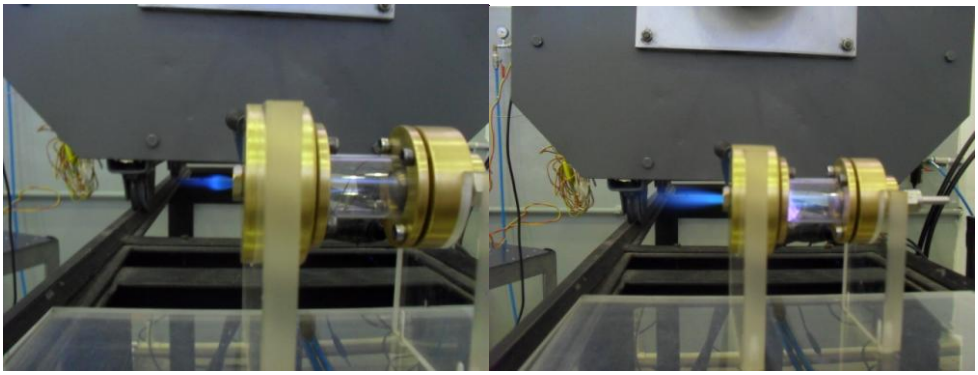

Fig.1. Flame sustained without plasma (a) and with plasma (b). Equivalence ratio of 1.3.Plasma power approximately 395 W

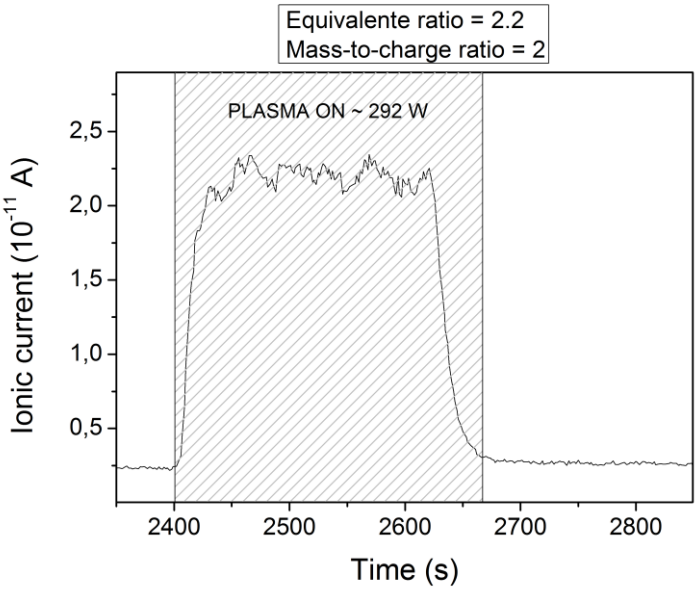

Fig.2 Temporal evolution of the signal corresponding to a mass-to-charge ratio of 2 (H_2^+)

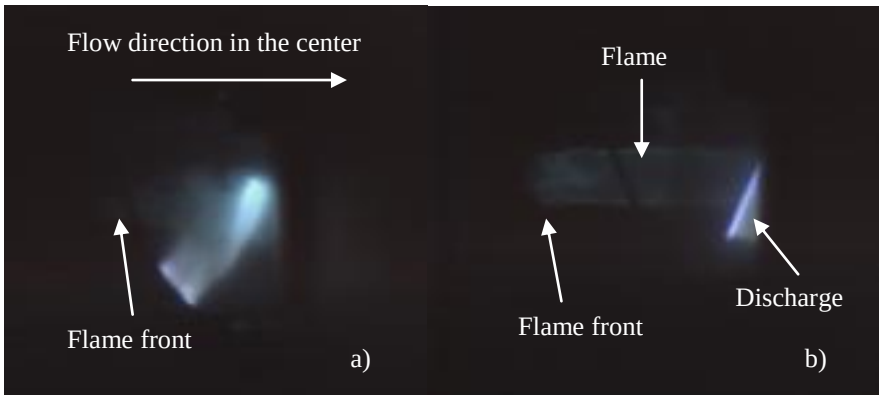

Fig.3. Images obtained with a high speed camera (1000 frames/s) Equivalence ratio of 1.4. Plasma power approximately 236 W

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Plasma-Assisted Combustion System with a High Power Density per Unit Area

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The subject of the paper relates to a usage of the plasma jets generated in the atmospheric pressure low-current discharges in a gas flow as applied the problems of ignition and flame control [1], [2] and the other applications [3]. The discharge, which is used for generation of the plasma jet at the exit of plasmatron, has essentially nonsteady-state properties. In the typical regimes of operation, due to the glow-to-spark transitions, the high-current spark pulses with a duration of about 100 ns are superimposed on the nonequilibrium plasma of a glow-type discharge [2]–[5]. Such a regime had been successfully applied in the plasma-assisted combustion system for propane oxidation [1], [2]. In this paper, we present the results on the further development of the system with a purpose to enhance a power density of a torch flame at the exit of system.

Schematic of the experimental arrangement is shown in Fig. 1.

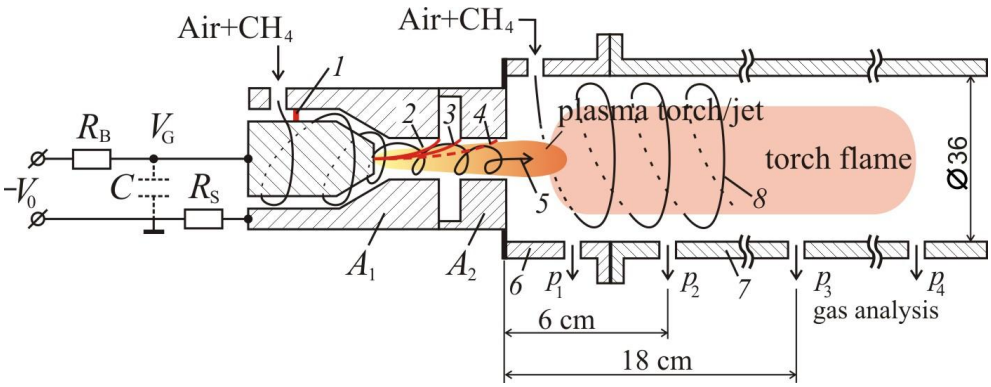

Fig.1. Schematic arrangement of the plasma-assisted combustion system

V_0 – Voltage of dc power supply. R_B – Ballast resistor. C – Capacitance of connecting cable. V_G – Voltage at the plasmatron gap. R_S – Current shunt resistor. (1 – 4) Positions of the plasma column at different instants of time. (5) – Vortex gas flow for plasmatron. (6) – Intermediate combustion chamber. (7) – Main combustion chamber. (8) – Vortex gas flow for combustion chamber.

Negative output voltage of a dc power supply V_0 with a maximum V_0 value up to 5 kV is applied between the cathode and the anode via the ballast resistor R_B. The values of the ballast resistor were R_B = 10.5 kΩ, R_B = 20.4 kΩ, and R_B = 47 kΩ. Changing the output voltage V_0 and the resistor R_B allowed us to change an average discharge current in a range

from i = 0.05 A (when an average power dissipated in the discharge Q = 60 W) to i = 0.2 A (Q = 150 W).

The air-methane composition was delivered in the plasmatron nozzle via a swirling unit so that the discharge was sustained in a vortex gas flow. The air flow through the plasmatron varied from G(air) = 0.35 g/s to G(air) = 0.55 g/s that is a longitudinal velocity of the air at the exit of the plasmatron nozzle varied from 14 m/s to 22 m/s.

In each set of the experiments, we typically fixed the air flow and added a fuel thus changing the stoichiometric ratio of the air-fuel composition. To characterize a relation between the air and the fuel, it is convenient to use an air excess coefficient. As applied to the experimental conditions under study this coefficient is determined by the relation:

$$\alpha = 0.0643 \times G(\text{air})/G(\text{fuel}), \quad (1)$$

where G is the gas flow in grams per second. Then, proceeding from the reaction of complete methane oxidation it can readily be seen that the air-to-fuel ratio α = 1 corresponds to the stoichiometric blend.

Figure 1 shows that the air-fuel composition is delivered in the intermediate combustion chamber 6 independently and also via a swirling unit. Due to burning of this fuel, the torch flame appears in the main chamber 7 and at its exit.

In the experiments, we used the stainless steel chamber with water or air-cooling of the wall. The chamber was equipped with the ports (p_1 – p_4) for the flue gas chemical diagnostics. These ports were also applied for measuring a gas temperature by means of the thermocouples. With a purpose to obtain the photographs of the flame, we also applied the quartz chamber 7, with an inner diameter of 40 mm. An example of a photograph of the torch flame with the quartz chamber is shown in Fig. 2.

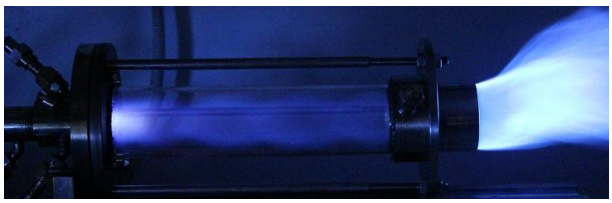

Fig.2. Photograph of the torch flame in the quartz combustion chamber for the case of rich air-fuel composition. Excess air coefficient for the plasmatron: $\alpha_{pl} \approx 1$. Excess air coefficient for the combustion chamber: $\alpha = 0.75$.

Thus, in this system, a kind of a hybrid concept is applied [2]. An average electrical power consumed by the plasmatron is only of (100–200) W. This power is necessary to activate the air/hydrocarbon mixtures and to sustain the oxidation processes in the plasma torch of the plasmatron. Typical heat power generated in the plasma torch due to the fuel oxidation is at a level of 1 kW. This heat power, in turn, is intended to sustain the main burning process in the combustion chamber where the torch flame is generated. As a result, in the combustion chamber, we obtain the flame with a high power density per unit area. In the experiment, the total heat power at the exit of the chamber can reach of about 10 kW, i.e. the power per unit area reaches of 1 kW/cm^2.

The burning process in the main combustion chamber is sustained in a wide range of the excess air coefficient from α = 0.8 to α = 2.5. Depending on α, we can obtain the complete fuel oxidation both at a small distance from the plasmatron nozzle (about 6 cm, when $\alpha \approx 1$) and at a distance corresponding to the exit of the chamber (30 cm). One of the illustrative cases is related to the situation of a rich air-fuel composition with α = (0.6 – 0.75). Just such

conditions are shown in Fig. 2. This is understandable that even at the end of the main chamber 7 the fuel is not able to burn off completely, and we see the torch flame after the exit of the chamber. This flame forms due to the fuel oxidation in the surrounding atmospheric air.

Based on the results of the experiments, we have constructed the independent combustion system (torch flame generator), which can be applied for different applications (Fig. 3). In particular, the generator has been installed in the system for sustaining the burning process in the installation for incineration of the oil slime. The results are presented in another paper of these Proceedings.

Fig.3. Photograph of the torch flame generator and the combustion chamber with the torch flame at its exit

(1) – Basis flange at which the torch flame generator is located. (5) – Combustion chamber. (F1) – Air/methane for plasmatron. (F2) – Air/methane for combustion chamber. (PS) – Power supply for plasmatron. Air expenditure G(air) ≈ 1.4 g/s, $\alpha = 0.64$

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Low-Current Nonsteady-State Plasmatron in a System for Utilization of the Oil Slimes

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In our previous paper [1] we had describe the plasma catalytic module for utilization of the oil residuals (oil slimes) based on a one-electrode high-frequency discharge with a power of several ten kilowatts (f = 13.56 MHz). Subsequently, the installation had been rearranged and modernized. Schematic arrangement of the modernized installation is shown in Fig. 1.

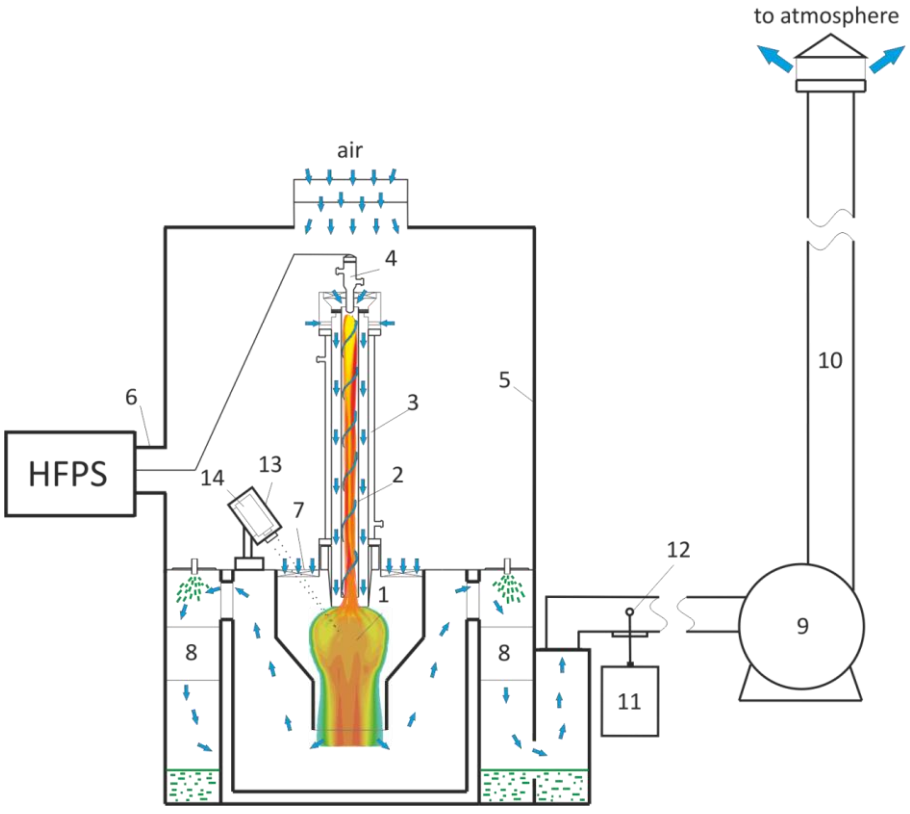


Fig.1. Schematic arrangement of the plasma catalytic module based on the high-frequency discharge

(1) – Plasma torch of the discharge in the combustion zone. (2) – Quartz tube. (3) – Water cooling metal case. (4) – Water cooling electrode. (5) – External case of the installation. (6) – Coaxial connector. (7) – Slide valve. (8) – Scrubber. (9) – Powerful exhaust fan

As Fig. 1 shows, the high-frequency plasma torch generator is located in the upper part of the system. The burning process for a water/fuel composition is sustained in the combustion zone 1 in the lower part of the system. The powerful exhaust fun 9 provides the air flow both for the high-frequency plasma torch and for the combustion area 1. The directions of the air

flow are shown in Fig. 1 by the arrows so that it is seen that the area 1 is fed with the air via the slide valve *7* with a controllable cross section.

The plasma torch generator based on one-electrode high-frequency discharge is a rather intricate and expensive unit. Then, the principal idea of this work was to replace this generator by the unit with the low-current plasmatron, which produces the torch flame with a heat power of about 10 kW [2], [3]. Schematic of the system with the torch flame generator is shown in Fig. 2.

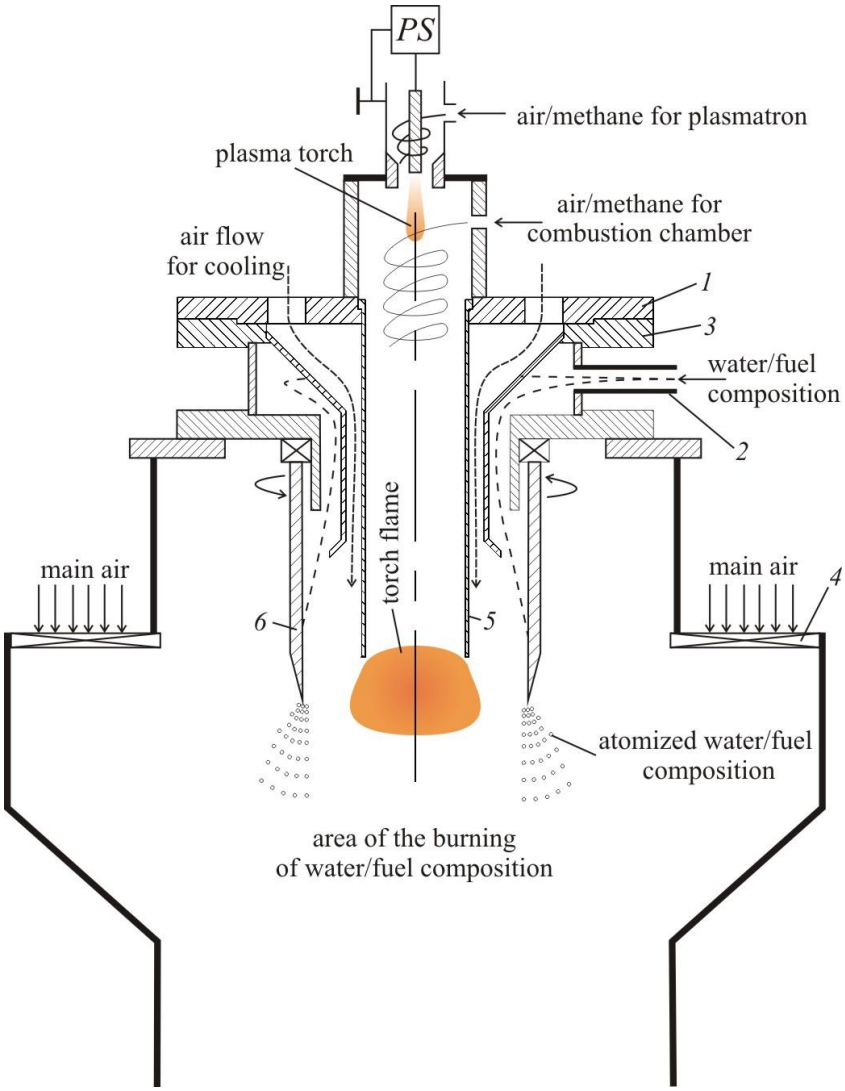


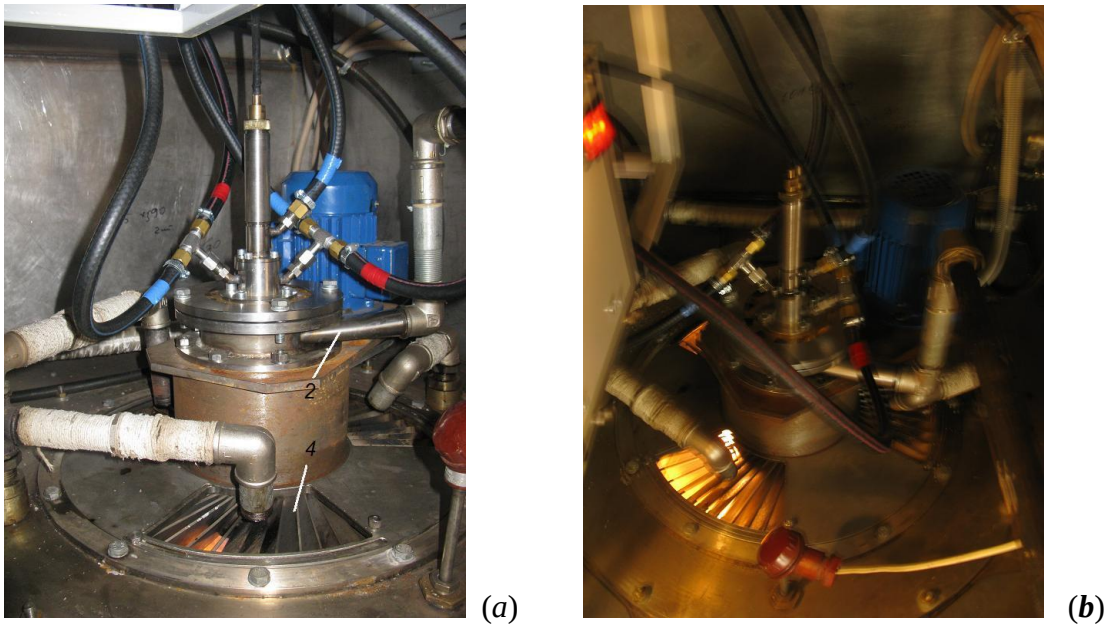
Fig.2. Schematic of the system for burning of a water/fuel composition equipped with the atmospheric pressure torch flame generator

(1) – Flange at which the torch flame generator is located. (2) – Pipe for feeding the combustion area (area of the burning) with a water/fuel composition. (3) – Flange at which the torch flame generator is mounted. (4) – Sliding valve for feeding of the combustion area with air flow. (5) – Combustion chamber of the torch flame generator. (6) – Rotating cylinder for atomization of the water/fuel composition

When compare Fig. 2 with Fig. 1, we can see that to sustain the burning process in the combustion area, we use the torch flame, which forms in the chamber *5* [2], [3] instead of the plasma torch of the one-electrode high-frequency discharge.

The oil slime represents a fuel whose main components are as follows: the oils, the tars, the asphaltens, and the mechanical impurities (mud, clay, and sand). This fuel has a high viscosity and can be atomized if only the units in the lower part of installation (especially the rotating cylinder *6* and the conical part of flange *3*) have a high temperature. To achieve a high temperature, at the first stage of kindling, we deliver diesel oil into the pipe *2* with a typical expenditure of about 180 liter/hour. At the second stage, we gradually replace the diesel oil by the fuel based on the oil slime and the installation starts running in the regime of normal operation with the water/fuel composition expenditure of about 600 liter/hour.

At the photograph in Fig. 3 we can see the burning of the fuel in these regimes via the sliding valve *4*. Thus, the mail conclusion of these tests is that the torch flame generator can be used in the installation instead of the high-frequency torch.



(*a*) (***b***)

Fig.3. Photographs of the upper part of the system in the conditions when the lower part is fed with diesel (a) and water/slime composition (b). (2) – Pipe for feeding the combustion area with fuel. (4) – Sliding valve for air flow.

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Laser Plasmochemical Method of Investigating Solid Compounds

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One of the most interesting effects of interaction of laser radiation with chemical combination is an opportunity of occurrence above a surface of targets of laser erosive plasma (LEP) [1]. If to create requirements when in plasma formed the longitudinal current on a selfcontained circle it is similar to a toroidal magnetic trap for which necessary the requirements when magnetic lines selfcontained and parallel an axis of a torus. In this case the particles of plasma inside a torus should be retained and move on a closed ring. Movement of plasma in a magnetic field can be or laminar, i.e. similar jet (Fig. 1 a, б), or turbulent, i.e. vortical (Fig. 1 c).

As have shown effects of optical-spectral researchs, on various distances from a surface of irradiated inorganic polymers at fluence of laser radiation in a gamut of $10^3 \div 10^{10}$ Vt/sm^2 it is possible to bleed three characteristic zone differing in density of particles, their temperature and character gas-dynamic motion Zone 1 - the dense hot nucleus of a torch which absorbs laser radiation.

Zone 2 - a zone of the acceleration in which there occurs is a transferring a thermal energy of plasma in a drop energy of a directional gas-dynamic motion. Zone 3 - a zone in which the plasma clot, having reached maximal value of velocity, is sharply braked owing to interaction with air medium. In this zone there is occurs the reorganization of the gas-dynamic motion of plasma. The general shape, and also the sizes of a torch in axial and a cross-section appreciably depend on value of fluence of laser radiation q_u. Besides density q_u, other important factor influencing character of a heating and scattering LEP in an atmosphere of air, is a relation between time of activity of a laser impulse τ_u and time of gas- dynamic scattering of plasma τ_p, which is defined by a lifetime of plasma in the field of a hot nucleus of a cloud, that is quantity r_0/c_3, where r_0 - the initial size of a plasma cloud, the equal to radius of a stain of a focusing of laser radiation, c_3 - velocity of a sound in plasma. At interaction of impulses of laser radiation nano-second duration with substance, of a gas-dynamic motion of be carried out when $\tau_u > \tau_p$. Laser plasma leaves hot field in time t_p much less, than duration of the impulse activity on a sample. Really, travelling speed of plasma in a surface for a lighted sample $\upsilon = 10^7$ cm/sec (a mode of promptly modulated quality factor) and values of radius of plasma $r_0 = 10^{-2}$ cm, that

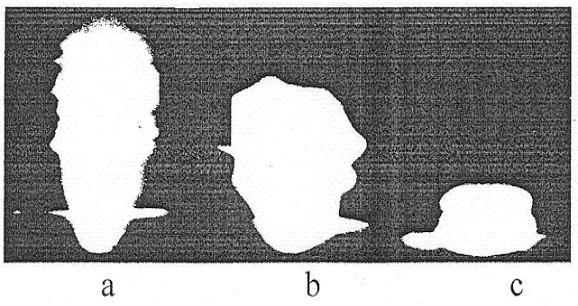
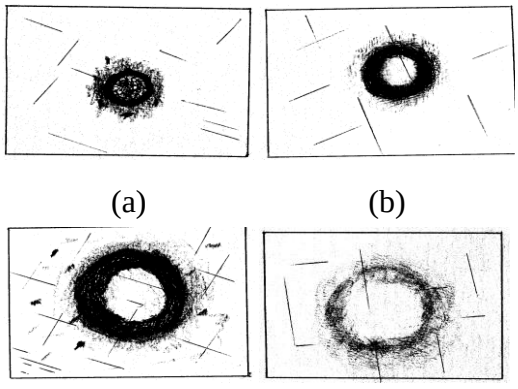


Fig.1. Profile of a torch of emission of substance:
a) *Loose oscillation of radiation,* τ_u *= 4 msec;*
b) *Passive modulation of quality factor,* τ_u *= 0.05 msec;*
c) Electrooptical modulation, τ_u *=30 nsec*



(a) (b)

(c) (d)

Fig.2 Formation and restructuring of a torch above a surface of a sample: a) on distance ≈ 10 r_k , b) on distance ≈ 15 r_k , c) on distance ≈ 25 r_k , d) Structure of a torch above a surface of a on distance > 40r_k

characteristic time of scattering will be equal $\tau_p = r_0 / \upsilon = 10^{-9}$ sec, while $\tau_u = 3 \cdot 10^{-8}$ sec, that is $\tau_p < \tau_u$. After that, as plasma leave field $r < r_0$ (Zone 1), it is accelerated and its further motion is defined by requirements of medium. Expansion of a plasma cloud in air occurs because of a lapse rate of pressure (Zone 2) and consequently characterized by the greater velocity in a direction, perpendicularly to an irradiated surface, than in a direction, collateral to it. Thus, as a first approximation it is possible to use the one-dimensional model of expansion of plasma with a density gradient. Absorbed energy of a laser impulse transfers in a drop energy of a directional motion of particles at adiabatic expansion of plasma as a result of a lapse rate of pressure. For nano-second impulses at fluence of radiation $q_u \approx 10^9 \div 10^{10}$ Wt/sm^2 velocity of expansion of achieves the asymptotical of value in current of time, approximately equal to half of duration of a laser impulse, and at distances from a place of formation of plasma about 10 r_0 , where r_0 - radius of the focal stain of laser radiation. Processes of stay of plasma in various conditions are partite in space, and in time. Plasma which has left area of a hot dense nucleus does not influence in any way area of a subsonic flow. After the plasma clot as a result of acceleration of achieves maximal value of velocity, he is sharply broken owing to interaction with an atmosphere of air medium. It explains occurrence of the secondary zone of an intensive luminescence of a torch. In this zone there is a reorganization of a gas - dynamic motion of a plasma cloud (Zone 3). In Fig. 2 (a), (b), (c) are shown the results confirming formation and reorganization of a gas-dynamic motion of a plasma torch. Photos are received on various distances from a surface of a sample which correspond to zones 1, 2, 3. In Fig. 2 (d) is shown the photo of plasma formation received on distance > 30-40 r_k. Occurs is a destruction of a plasma cloud and change of the temperature up to temperature of air (Fig. 2 d). The considerable interest for management of behavior of a motion of a gas - plasma cloud in air is represent opportunity of its formation experimentally set by us as a toroidal vortical ring. (Fig. 1 (c), 2 (b), (c) and (d). As shown of results provide good reproducibility of dynamic and spectral characteristics of plasma torches. Optimum value of density of a stream of laser radiation is $q_u \approx 10^{10}$ Vt/sm^2. This mode provides steady character of gas-dynamic movement of torch LEP in an atmosphere of air and the best reproducibility of spectral characteristics of plasma. Using these characteristics of pattern helped apply of LEP in spectral analysis of solid samples (gold containing sulphide of ores and minerals). Application of emission spectra of LEP in analysis of the chemical composition has reduced detection limits to pictograms and relative detection of up of limits to 10^{-4} %. Accuracy is characterized by standard deviation equal to 0.04.

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Study of Behaviour of Plasma Arc for Ignition High Power Plasma Torch in MATLAB/Simulink

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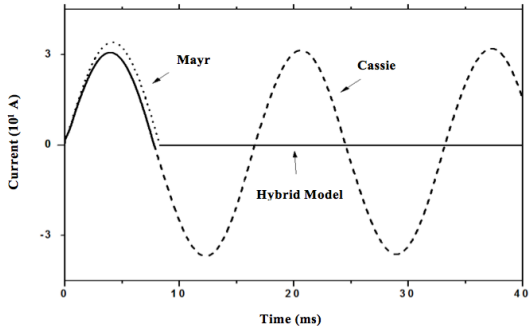
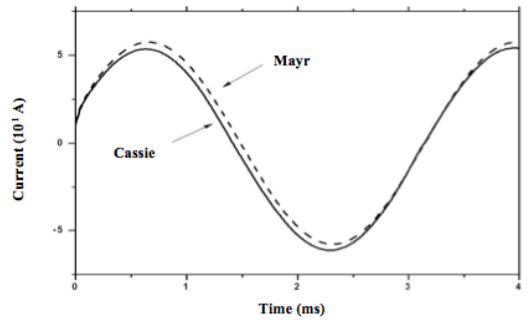
Due to the dynamic characteristics of high enthalpy plasma flow, plasma torch is a device suitable for treatment of solid waste using of plasma gasification system [1], [2]. The simulations arc ignition on AC and DC are presented in this paper based on the classic models Cassie and Mayr. The arc plasma behavior was studied through simulations, which is influenced by the system of the power source [3]. This study aims at building a prototype of high power plasma torch.

Each plasma torch design needs unique characteristics for ignition; these characteristics are defined using simulations in AC or DC. To avoid problems in the network switching, the simulations were compared, and the parameters or ideal ignitions conditions were set [4].

For the simulations in AC, a test circuit was designed. It was used to analyze the power parameters such as the choice of the time contacts separations, peak input voltage and the adjustment of the arc model. Fig. 1 (a) shows the simulations of the hybrid model (Cassie and Mayr). The solid line corresponds to the behavior of the arc; it coincides with the Cassie Model to 8.33 ms. At this time, the breaking of the arc occurs; thus, it is possible to analyze the proximity of the current to the zero, where the arc is turned on or extinguished. From this moment onwards, the behavior of the arc can be described by using the hybrid model [5], [6]. It was found that the maximum value of the input peak voltage was 80 kV. This voltage is not enough for the performance of high power plasma torch, since the breaking time is not obtained; hence, the plasma tends to be extinguished, as shown in Fig. 1 (b) [7].



(a)



(b)

Fig.1. (a) Current as function of Voltage of Mayr and Cassie for input peak voltage from 60 kV, (b) Current as function of Voltage of Mayr and Cassie input peak voltage from 80 kV

For the simulation in DC, a configuration for plasma arc circuit was proposed, which includes a source of AC input voltage, a DC power source with the control system, and an output inductor current. This inductor regulates the instability produced by the negative resistance of the arc [8]-[10]. In the simulation, it was varied the load voltage during the ignition phase, and also the parameters which affect the arc stability at the steady state (i.e., the mass flow, the power released arc, the voltage, and the current transitions). This variation took the

form of an adjustment of these parameters to the general operating conditions and the electrical specifications of the prototype, as portrayed in Table 1.

Table 1. General condition for operation and electrical specification for plasma torch prototype

Electrical Specification	**Value**
Output power rating	300 KW
Input voltage rating	12 KV
DC arc voltaje	500 V
DC arc current	600 A
Input Frequency	60 Hz

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He presented Analisis de los Modelos de Arco Electrico a presion atmosferica in the 3rd National Congress of Engineering Physics, in September 2012.

Ion Beam Diagnostic Tool for Plasma-Surface Interactions in Plasma Thruster Discharge Regions

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Massachusetts Institute of Technology's Space Propulsion Laboratory (SPL) and Plasma Surface Interactions Science Center (PSISC) have developed and is currently testing a diagnostic tool for investigating plasma-surface interactions in plasma thrusters. This tool uses the PSISC's Cambridge Laboratory for Accelerator Study of Surfaces (CLASS) tandem ion accelerator to determine erosion/re-deposition rates for plasma thrusters and fusion devices using ion beam analysis (IBA) on the discharge region of the thruster before and after exposure to the thruster's plasma.

IBA is a useful tool for studying surfaces in EP thrusters because it is a fast, direct, non-destructive technique which outputs high resolution results that can cover a wide range of elements (including crystalline and amorphous materials), and can be performed without any special specimen preparation. In addition, IBA can be applied without dismantling the device itself. As long as the paths of the incident beam and the scattered ions/radiation are not obstructed, IBA can be applied directly to interior surfaces without requiring disassembly or damage to the device.

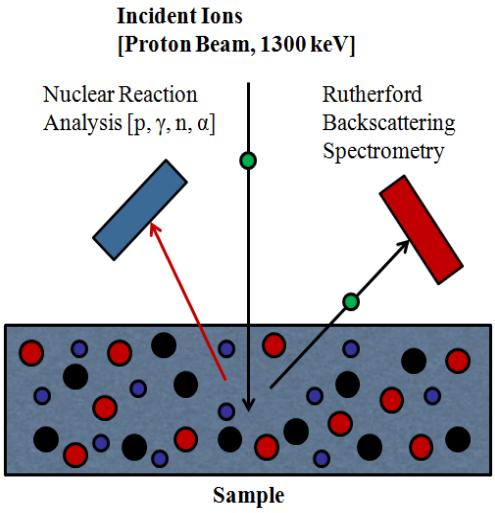

Fig.1. Schematic for Ion Beam Analysis (IBA) methods of Rutherford Backscattering Spectrometry (RBS) and Nuclear Reaction Analysis

Ion Beam Analysis

The particular IBA methods used for these erosion studies include Rutherford Backscattering Spectrometry (RBS) and Nuclear Reaction Analysis (NRA). For general profiling of a surface, RBS is used due to its great versatility in determining surface composition. During RBS, an incident proton ion beam is fired at high energies (~1300 keV with the CLASS accelerator) at a target surface. Upon collision, the protons backscatter away and are collected by a detector. The detector collects counts of the backscattered protons, which are compiled into an energy distribution or spectrum. Given that the energy of the collected protons directly correlates with the material which the protons backscattered from, the structures in the spectrum can be used to identify the material present in the target.

In comparison, NRA is used only when there is a material in the target which creates a nuclear reaction when in contact with the incident ion beam. The implantation of the volatile material is performed in order to create clearly defined depth markers in the material - the depth of implantation is directly correlated with the energy of the implantation beam and the concentration of the implanted material is proportional to the implantation time. The nuclear

reactions caused by proton impingement generate higher energy particles/radiation (alphas, gammas), which can be similarly collected by detectors with aluminum foils to cut down the lower energy backscattered proton flux. The energy levels of the output particles/radiation are directly correlated to the depth of the marker: the deeper the marker, the lower the energy.

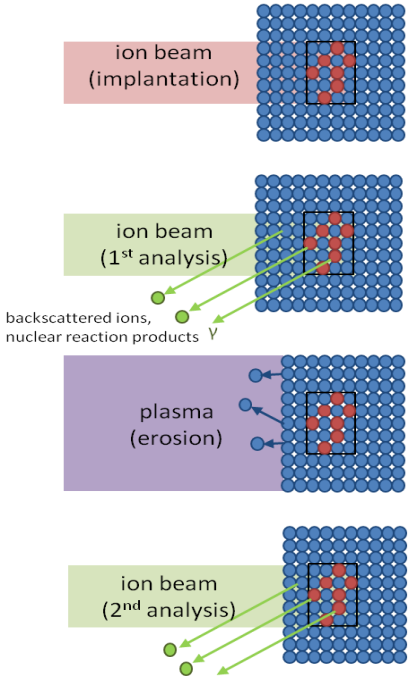

Fig.2. Calibration and validation scheme

Procedure for Erosion Characterization

The net erosion and re-deposition rate of the thruster post-firing can be found by fitting the RBS spectrum to simulated profiles and then comparing the changes in the IBA profile. The procedure for calibrating and validating IBA for characterizing erosion in materials typically used in Hall thrusters is as follows: lithium is implanted at a known depth (3-5 microns) and concentration (5%) into a coupon (sample material includes alumina, aluminum, boron nitride, diamond) with a beam of known diameter (1-3 mm). Subsequently, RBS/NRA is performed on the implanted coupon to establish the baseline profile. After the initial profiling, the sample is exposed to helicon-generated plasma with characteristics similar to thruster plasma. Once the sample is eroded to the desired depth, additional IBA is performed on the coupon. The generated profile is compared to the pre-erosion profile and the resulting comparison yields the erosion measurement.

Calibration of the IBA-obtained erosion measurements will be performed via comparisons with optical volume measurements of eroded regions.

Initial Results and Planned Future Work

After a large array of tests, the IBA-determined depth measurements have well correlated with predictions and validation of the IBA technique from comparisons with other surface profiling techniques is pending. Once IBA is validated in this fashion, experiments can transition from coupon samples to the use of the insulating materials from existing electric propulsion devices. In this case, we plan to use the boron nitride insulating cone from the MIT Divergent Cusped-Field Thruster (DCFT), which is a specialized type of Hall thruster previously tested in longevity experiments.

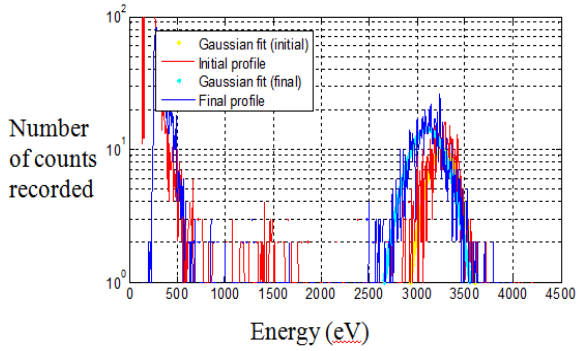

Fig.3. Spectra of Li-implanted aluminum coupon, before and after erosion. Net deposition is calculated to be 650 nm

After lithium implantation and initial profiling, the boron nitride is exposed to the DCFT's native discharge rather than the helicon-generated plasma. The erosion rates determined by the differential eroded depths

recorded by IBA can then be compared to the profilometer-recorded erosion rates obtained in past AFRL-hosted longevity experiments. If this comparison is favorable and repeatable in subsequent trials, then IBA can reasonably be determined as an advanced, expedient and suitable diagnostic tool for erosion studies of plasma propulsion devices and their respective prospective insulating materials.

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Atmospheric Plasma Discharges for Sterilization Studies

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Sterilization refers to any process that effectively kills or eliminates transmissible agents (such as fungi, bacteria, viruses, prions, spore forms, etc.) from a surface, equipment, foods, medications, or biological culture media. In general, surgical instruments and medications that enter an already sterile part of the body (such as the blood, or beneath the skin) must have a high sterility assurance level (SAL). In order to reach this SAL, several sterilization agents have been applied: heat, steam under pressure, radiation, electron beam, and chemical products. However, none of the sterilization methods available has a universal application, and the choice of the ideal technique depends on the physical and chemical properties of the materials that are going to be sterilized. The use of non-thermal plasmas on sterilization has been recognized as a successful technology for it congregates safety, effectiveness and quickness. Although called plasma sterilization systems, the equipment available on the market today have as primary sterilization agents the Hydrogen Peroxide and Peracetic Acid, and the plasma phase is responsible mainly for the removal of toxic residuals from the surface of the sterilized material.

The present work is based on the assembly and adjustment of a corona discharge (initially developed for pollutant control experiments) for sterilization studies at atmospheric pressure. We used ordinary air as the precursor gas and AC voltages of 16.3 kV and 60 Hz. In microbiological validation, we used *G. stearothermophilus*' spores, considered one of the most resistant to the plasma sterilization process. Due to the low electric currents, the average power of the system was 14.6 W. The decimal reduction time of viable spores was 8.40 minutes. We associated this result to the positioning of the biological samples in our device and the low power of our system. We also associated the biocidal capability of the plasma to variations on the relative humidity of the air. These variations lead to changes in the concentration of reactive species produced from dissociation of the water molecule in plasma such as the hydroxyl and some oxides. Nevertheless, we observed the elimination of all viable spores after 40 minutes of exposure to the plasma.

Moreover, we reviewed the history of plasma sterilization and the main features of the various gas discharges and plasma sources used for sterilization.

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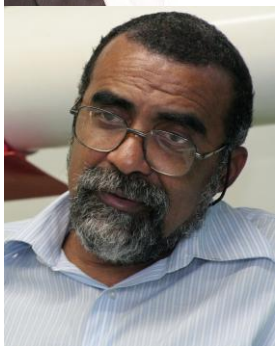
He has worked with the development and characterization of plasma sources for sterilization studies and space propulsion. He is currently a Specialist in Regulation and Health Surveillance (area: physics) with the National Health Surveillance Agency (ANVISA), Brasilia.



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He has worked with the development of several plasma sources for various purposes, namely, space propulsion, pollutant control, and magnetic confinement. He is currently an Associate Professor with the Institute of Physics at the University of Brasilia

Formation of Different Core-Corona Structures in the Discharge Channel during the Wire Explosion

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In the numerical calculations it was obtained that, during the explosion of a single aluminum wire, the core material remains for a long time in the state of a dense nonideal plasma with a temperature of 1–3 eV. Only after shunting the main part of current to the corona, the core goes into a two-phase liquid-vapor state in the expansion process [1].

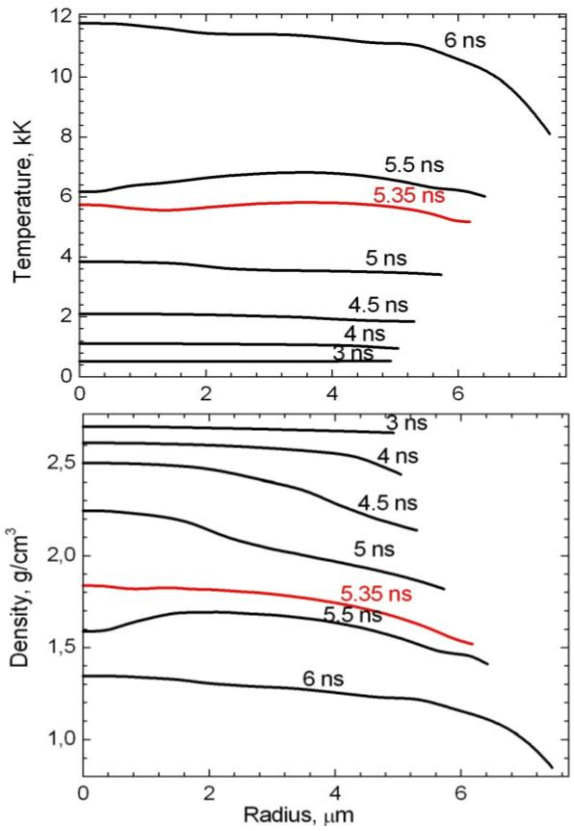

Fig.1. Results of MHD simulation of aluminum wire explosion during initial stage

However, if shunting of the current occurs at an early stage of the explosion, for example, when the wire material is still in liquid state, it is possible another scenario of core structure formation. In this case, due to a sharp drop of the compressive magnetic pressure, the core material can come into a state of the stretched melt during unloading.

For studying the dynamic of decay this metastable state the joint magnetohydrodynamics (MHD) and molecular dynamic (MD) numerical simulations were performed. At the first stage the "cold-start" simulations were performed in the framework of a one-dimensional one-temperature MHD model. In these simulations, the table data on the properties of aluminum [2] were used. The tables of thermophysical properties were constructed according to the equation of state (EOS) model [3], describing phase transitions (melting, evaporation, etc.) and metastable states of matter. The electric conductivity was described according to [4]. An aluminum wire with a diameter of 25 μm at room temperature and the zero current were taken as initial data.

Magnetohydrodynamics modeling, widely used for simulation of wire explosion, cannot trace the complex vapor-liquid flows including kinetics of nonequilibrium liquid-vapor phase transition associated with void formation and cavitation in stretched metastable liquid. For the first time, we performed molecular dynamics simulations of exploding wires, which are able to reproduce such complex flows. So at the second stage of MD calculations results of MHD simulations were used as initial data (see Fig.1).

One of the most important requirements for realistic MD simulations is the availability of accurate interatomic potentials suitable for simulation of materials at extreme conditions. To this end, we employed an EAM potential for Al that has been recently developed specifically to simulate the metal's response to a wide range of compressive and tensile stresses [2]. In our MD simulations, the cylindrical samples, representing single wires in vacuum (with radius R and length l_z = 40.2 nm, where the dimension l_z was subject to periodic boundary conditions), preheated to conditions taken from MHD simulation at time 5.35 ns was performed with: initial density of melt 1.8 g/cm^3, temperature 6 kK, pressure 2.6 GPa. MD simulations were done for different radii of wire: 50, 100, and 200 nm (see Fig. 2 for last radius). The last was done with 2048 CPUs. Simulation of wire with larger radius R requires ~500·(R/100nm)2 CPUs, however our results show good similarity of expansion flows in wires with different radii. Therefore, MD results can be extrapolated to micron-sized wires.

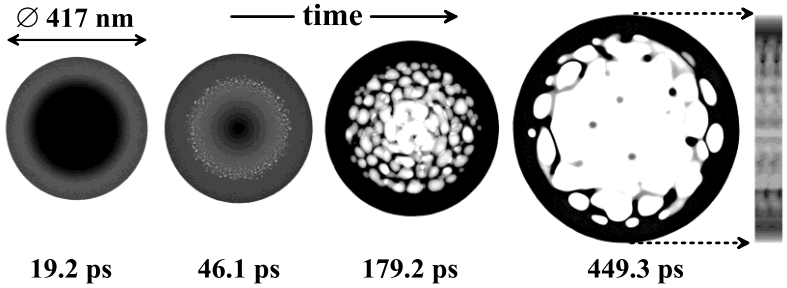

Fig.2. Snapshots of density map $\rho(x, y)$ averaged over wire length l_z = 40.2 nm. Wire had R = 200 nm, T = 6 kK, P = 2.8 GPa at cutoff of current

After cutoff of current the supporting magnetic pressure disappears and wire begins to expand freely. Radial rarefaction wave starts from surface and propagates toward the center of cylinder, see snapshot at 19.2 ps. Rarefaction/tensile wave produces the fast drop of density of melt below equilibrium liquid density, pressure goes to negative range, and metastable stretched melt is formed in the interior of wire. At pressure –0.5 GPa and strain rate $2\cdot10^9$ s^{-1} the bubble nucleation starts on r = 140 nm. The liquid shell of 40 nm thick is formed, see snapshot at 46.1 ps.

We can see that in accordance with the molecular dynamic calculations this metastable state decays, that resulting in to formation of a complex core structure: the outer cylindrical liquid shell filled with low-density foam. The foam decays into liquid droplets before the outer shell breaks apart. Simulated density profiles demonstrate good qualitative agreement with experimental high-resolution X-ray images (see Fig. 3) showing the complex hollow structures within the long-living dense core. We can see also that core structure differs along wire length: we see film density profile which corresponded to almost homogeneous matter distribution in core cross-section (Fig. 3*d*) but in all the rest (Fig. 3*e–i*) we see profiles which corresponded to hollow structures with different thicknesses of liquid wall and different relations of wall densities to inner one. If we assume that current cutoff is non simultaneous

process along wire length namely such picture would be observed in X-ray image. Really, at earlier cutoff the energy deposited into core is smaller than atomization enthalpy and it is realized the scenario of the core formation presented above (obtained in MD simulation). But if the energy deposited into core is large than atomization enthalpy (later cutoff) it is realized the scenario of the core formation presented in [1] (obtained in MHD simulation). So we can state that according to experimental and numerical data the core structure depends on time of current cutoff.

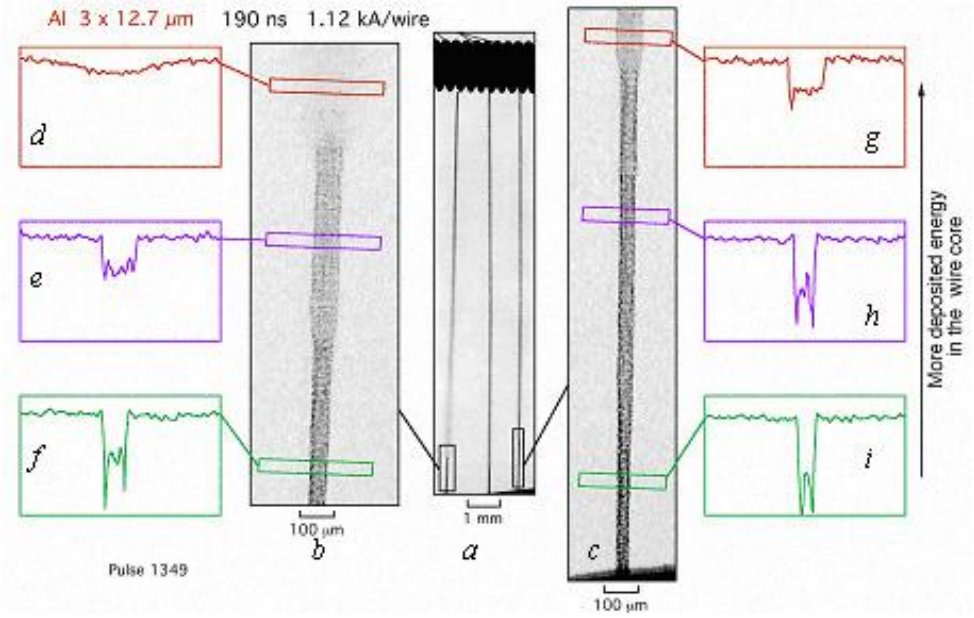

Fig.3. (a) X-ray radiograph image of the heterogeneous material distribution in exploding 3 parallel Al wires, (b and c) part of image (a) in large scale and (d-i) film density profiles across the image averaged over a vertical height indicated by the boxed regions in (b and c). Initial wire diameter was 25 μm [3]

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Water Steam Plasma Equipment

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Water plasma is very perspective for many applications due to its ecological compatibility, high enthalpy, oxidizing-reducing nature, thermal conductivity, not scare resources, etc. Thermal efficiency is the most important parameter for using such plasma in industry with high profit. We report here the technological water steam plasma equipment with vortex DC transferred arc plasma torch cooled only by working medium and with special direct flow two-stage steam generator providing operating of arc chamber with efficiency of about 100%.

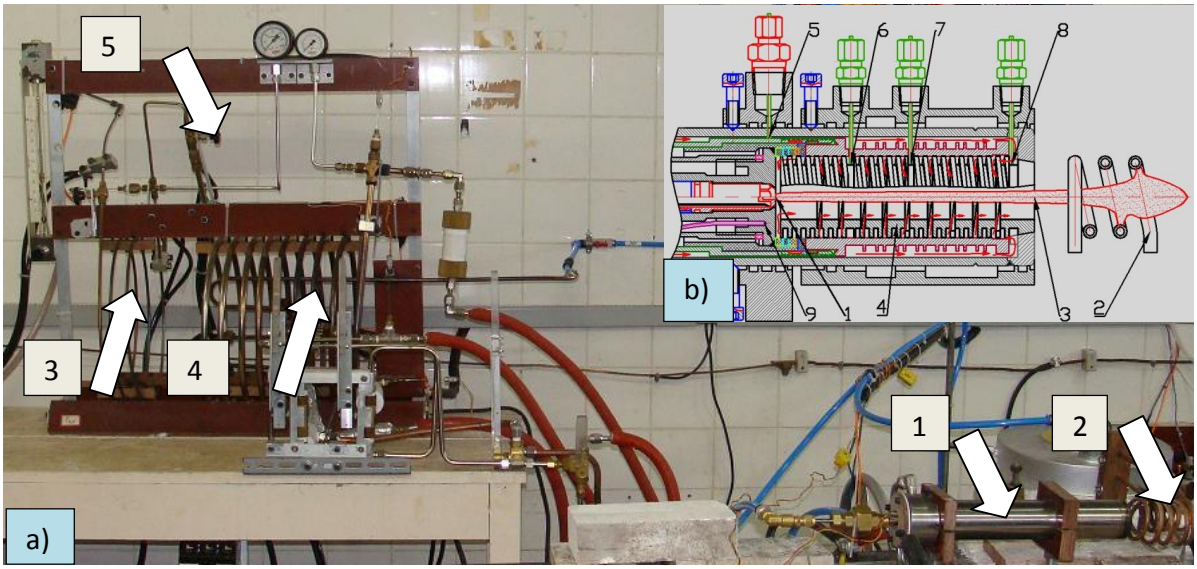

Fig.1.

a) Layout of plasma equipment
1 – plasma torch; 2 – auxiliary anode. 3 – steam generator (1st stage);
4 – steam generator (2nd stage); 5 – throttle

b) Cross section of experimental torch with thermocouples
1 – cathode; 2 – anode; 3 – arc; 4 – nozzle with distributed steam injection;
5-8 – nozzle thermocouples; 9 – cathode thermocouple

The torch has special design without conventional tangential vortex chambers and has been made in the form of simple steel tube with small diameter and with all external connections mounted only at its rear end. This makes it possible use of torch in hot

surroundings of plasma reactor. Owing to absence of conventional water cooling, internal gas-dynamics of torch appears to be a key factor for its thermal protection. Therefore internal gas-dynamics was set by study of the temperature field at vital points inside the torch by data acquisition system using thermocouples. The temperature of all parts contacting with steam has to be maintained during operation at level superior of 100 ^{0}C to prevent condensing steam and arc destabilizing. Therefore torch always was started with air and switched to steam after attaining the temperature of all parts superior of 100 ^{0}C.

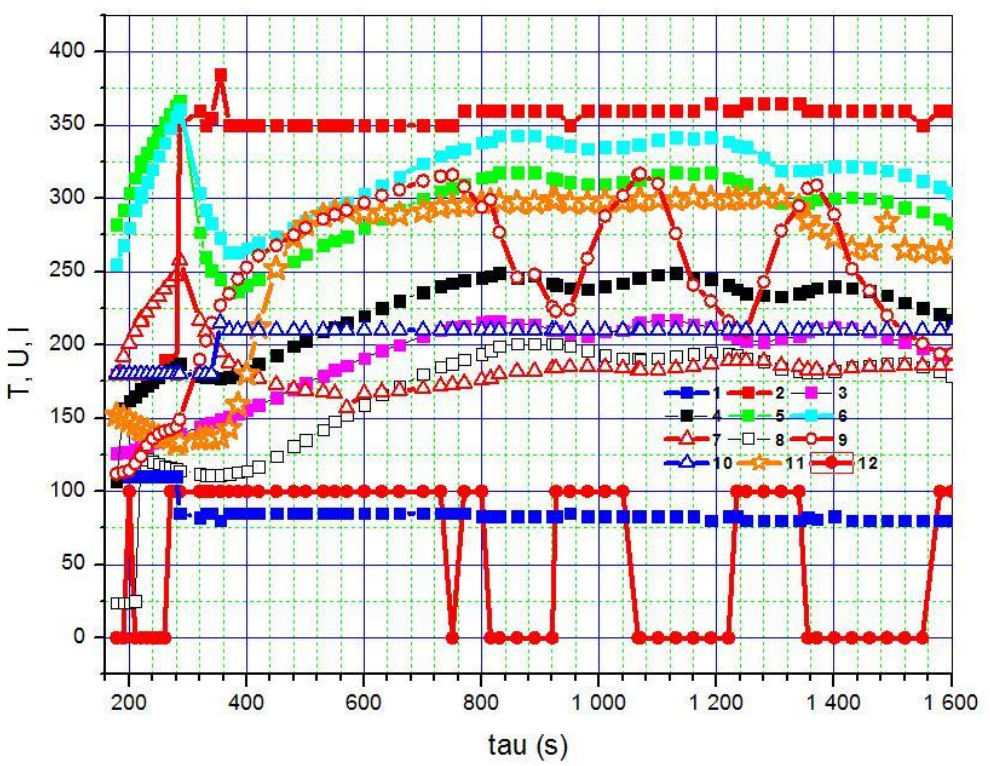

Fig.2. The record of the data acquisition system under variation of steam inlet temperature

1 – arc current, A; 2 – arc tension, V; Temperatures, ^{0}C: 3 – nozzle at point 5; 4 – nozzle at point 8; 5 – nozzle at point 7; 6 – nozzle at point 6 in Fig.1; 7 – cathode body at point 9 in Fig.1; 8 – external body of torch; 9 – steam at torch inlet; 10 – current of 2nd stage of steam generator, A; 12 – steam inlet torch heater on = 100; off = 0

Very critical part of setup is also special two-stage steam generator providing continuous superheated- or wet- steam supply necessary for operation and cooling the torch. External surface of the torch is also in need of cooling during operation in plasma reactor besides internal one. Integral heat of cooling is regenerated in our setup because only working steam is used as cooling agent excluding electrodes. Thermal loss to compact water-cooled Hafnium cathode comprises only 2.5% of electric arc power defining thermal efficiency of integral torch mounted upstream the reactor about 97.5%. An efficiency of the integral equipment including plasma reactor depends on exhaust thermal losses, thermal loss through water-cooled bottom electrode and through the walls. Besides efficiency, continuous running time is very important for technological plasma equipment. Therefore the next step will be adaptation the torch for operation with both fused metal renewable electrodes presenting a part of the plasma reactor. They reported in [1] thermal efficiency of such type reactor even with water-cooled torch about 92% during operation with water steam. Therefore we rely on efficiency substantially higher for our setup with regenerative cooled torch. Crucial function here belongs to two-stage steam generator. High pressure hot water undergoes there throttling

and generates at inlet of the second stage a gaseous medium in form of saturated steam possessing by almost total latent heat of liquid water and appropriate therefore for subsequent cooling of torch by superheating inside of torch. No condensation of steam is possible on the walls of second stage of steam generator or cooling jacket of torch owing to heat supply through these walls maintaining therefore them hotter than steam. No steam aggregation takes place also inside of steam flow according to our experimental verification. This appeared to be the solution of the problem of steam generating directly in cooling jacket of torch. Attempts of superheating of water directly in cooling jacket were made many times before; however they were unsuccessful or required filling of jacket with porous medium, complicating and raising the price of torch [2]. They referred this problem to non-stable process of explosive transition of superheated water to steam [3]. This phenomenon is dangerous if water exists in form of macro-drops inside of cooling jacket or steam generator. Such explosions are capable totally destroy the vortex stabilization of arc and destroy the plasma torch. Heating water flow of 1 kg/s from initial temperature of 100 ^{0}C to superheated steam of 500 ^{0}C requires in our design about 3 MW of energy. Typical enthalpy of water plasma applicable for the most technological applications comprises about 10 MJ/kg (3000 K of temperature). This means, about 30% of arc power we can absorb for cooling torch without loss of efficiency – this heat is included totally in plasma enthalpy. We use therefore our steam generator as cooling device for maintaining optimal thermal regime of torch by simple adjusting the electric power of the second stage. Depending on this power, torch is supplied by steam with content of water necessary for its effective cooling. As we already reported in previous reports [4], [5], the torch is capable to work both with wet and superheated steam. Thereby we just maintained optimal temperature at certain vital point chosen inside the torch by adjusting power of the second stage of steam generator. Here we made special simulation of thermal response of the torch on variation of temperature of steam at inlet. Special heater was connected just to the inlet of the torch and by its turning- off and -on we obtained thermal response of the torch in four points along the axis of the nozzle and at the cathode body. Only cathode body temperature measuring can be used in plasma reactor without complication of the design of torch. We show therefore in Fig.2 this response, which can be used as feedback for automatic control of thermal regime of torch inside the reactor.

During operation of conventional water-cooled plasma torch inside plasma reactor it absorbs much heat from the reactor and decrease thermal efficiency of total equipment. Our setup regenerates total heat of cooling returning it back to plasma. Besides, in conventional torch with water cooled external surface evaporated metal and slag from the reactor condenses at cold torch surface increasing its diameter and impeding extraction from the reactor if this is necessary during operation. Our torch has no any soft gasketings at the head part submerged to the reactor and no liquid water in cooling jacket. Therefore its temperature can be maintained elevated depending on material used for manufacturing of the external tubular body – up to 1500 K for super-alloys and even higher by making it from molybdenum, or by refractory rendering of the external surface. In addition, leakage of liquid water inside of incandescent interior of reactor containing big amount of fused slag and metal is highly explosive. Our torch with this respect is blast proof due to absence of liquid water.

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Approximation of Thermal and Electrophysical Properties of Steam and Other Thermal Plasmas for Calculation of Electric Arc on the Anisotropic Model and Physical Modeling of Plasma Arc Torches for Waste Gasification Reactors

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In the papers [1], [2], a so-called anisotropic model of an electric arc, which allows receiving power of a generalized expression for calculating the characteristics of the discharge in the plasma torch channel without a large number of experiments. The experiment only needed to test the theoretical formulas. The model is based on the degree of approximation of the temperature dependence of the electrical conductivity with different exponents along the longitudinal and transverse coordinate. Verification of the model, based on experiments on electrical arcs with a negligible blowing arc column with different gases (air, nitrogen, argon, helium), showed the effectiveness of this method [3]. Later, it was also carried out a comparison with numerical simulations and experimental data for hydrogen [4], which gave as satisfactory agreement. An important step towards the use of anisotropic model for practical purposes is the processing of data on heat and electrical properties of plasma gases to obtain the necessary parameters of the approximation. Due to the growing interest for steam plasma arcs for physical modeling of plasma torches to develop new and optimization of existing reactors for gasification and destroy of solid and liquid organic feedstock and wastes [5]-[7] and in accordance with the need to predict the current-voltage (CVC) and thermal characteristics of plasma torches are used, it is appropriate to make the said process and also for this plasma type. The data on thermal conductivity of steam plasma taken from [8], and on electrical conductivity - from [9]. These properties are treated in the temperature range (5–15)•10^3 K at a pressure of 0.1 MPa, which is the most typical levels of temperature electrical arcs in no extreme conditions. We used the approximation formula

$$\sigma/\sigma_0 = (\Delta S/\Delta S_0)^{n_\sigma}, \qquad (1)$$

which in dimensional form is written as

$$\sigma = a_\sigma \Delta S^{n_\sigma}. \qquad (2)$$

The calculating defined aspect ratio and an exponent. This procedure is preceded by evaluation of the integral $S = \int_0^T \lambda dT$ for heat conductivity potential. Entering the value on the boundary conductive zone previously determined by linear approximation based method of least squares. After that, the same method to process data in the form of (1) or (2).

Approximation of the dependence of the electrical potential of the steam plasma conductivity is shown in Fig. 1. Linear approximation is described by

$$\sigma = 0,221\Delta S, \quad (3)$$

and power one as

$$\sigma = 44,51\Delta S^{0,484}. \quad (4)$$

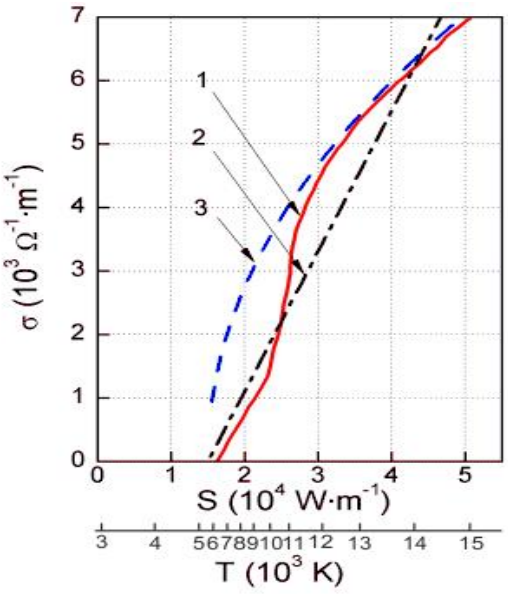

Fig.1.

For the generalization see in the Table also the approximation parameters for other gases that are often used as plasma gases - air, nitrogen, argon, helium [3] and hydrogen [4]. Using a modification of the method we have developed a physical model for the case of arcing vapor plasma arc torches calculating characteristics carried out in accordance with. Previous assessment of partial effects of all elements of energy equation (with attribution of characteristic values of these elements to the values of joule heat emission) shows that energy transfer affected mainly by convection factor as well as radiation and plasma flow kinetic energy ones. With considering of dimensionless form of basic heat, mass and electric charge

Table 1. Initial parameters and approximation of heat and electrical properties of plasma-forming gas at P = 0.1 MPa

Parameter	Units	Steam [8],[9]	Air [3]	Nitrogen [3]	Argon [3]	Helium [3]	Hydrogen [4]
Range of T variation	10^3 K	5–15	4–15	6–15	3–15	4–15	2–25
T_*	10^3 K	6	7	6.83	7	7.47	7.1
S_*	10^3 W/m	15.48	5.42	5.76	0.71	7.95	3.54
T_0	10^3 K	10	10	10	10	10	10
ΔS_0	10^3 W/m	8.51	5.88	6.14	0.99	5.47	11.58
σ_0	10^3 (Ohm·m)$^{-1}$	3.57	2.15	3.12	2.5	0.054	1.49
n_σ	-	0,484	1,25	0,827	0,54	2,75	1,176

transfer equations the defining criteria for convection factor and radiation and conduction ones can be transformed to the form such as: $\pi_{CONV} = I^2 / (Gd\sigma_0 h_0)$. As generalized function

(output dependent parameter) of electric charge transfer can be used a voltage U of electric arc or as the better variant the such number as $\pi_{DEP} = Ud\sigma_0/I$, which is a generalized electric resistance of a torch arc and is quite typical for application in the physical modeling for generalization of CVC of many types of torches [10], [11]. As a possible application of this new modification of the method of physical modeling of electric arcs in the case of steam plasma can the design of high efficient power (up to 300 kW and above) torches with non-transferred and transferred arcs, that are developed during last years for air and steam plasma gasification reactor for municipal solid wastes, coal and petrochemical residues [12], [13].

Symbols

T - temperature; λ - thermal conductivity; σ – electric conductivity; S – heat conductivity potential; $\Delta S = S - S_*$; a_σ - aspect ratio; n_σ - the exponent. Indices: $*$ - border of conductive zone, 0 - characteristic value of magnitude.

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Some Results of Development and Experimental Investigations of High Power and High Pressure RF Torches with Reverse Vortex Plasma Stabilization

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Interest in commercially available high power and multi-gas plasma torches with extended lifetime to thousands of running hours without maintenance grows worldwide due to advantages of the plasma based technologies. As the best candidate to satisfy these requirements was selected a radio-frequency (RF) torch also named inductively coupled plasma (ICP) mainly because of its electrodeless design. Unfortunately, all known before RF plasma systems had some disadvantages, which limited their application, as low plasma gas flow, difficulties with ignition at 1 bar pressure, relatively low efficiency of power transfer, need in a specially designed power sources, etc. So, the main efforts of our recent R&D were focused on overcoming above negative features plus on jumping into the new for RF plasma area of elevated pressures.

Every plasma system consists of a torch and a power supply. We already reported in [1], [2] development of a range of torches with output plasma power from 30 kW to 500 kW with plasma stabilization by reverse vortex. The last year efforts were devoted mainly to development of the high pressure devices, power supplies exclusively for RF plasma torches, and remote plasma initiation. To perform investigations was developed an experimental set up as shown in Fig.1, including integrated type power supply with 60 kW power input connected with a capacitor bank and torch by a 3 m length RF cable, water cooled high pressure chamber, gas supply system, and control system enabling remote ignition, calorimetric measurements, and entire system protection.

Fig.1. View of the experimental set-up for high pressure operation

Fig.2. Torch in operation in the open air

Improved for high pressure operation RF torch has a ceramic insulator to withstand thermal shork at ignition and elevated pressure, and two swirlers to compare thermal efficiency with direct and reverse vortex plasma stabilization. Its installed on a water cooled chamber with regulative pressure which absorbs heat of the plasma plum. The power supply was designed and build by APT, LLC for further commercialization, but was additionally equipped by the water flow meters and thermoresistors in three separate lines – electronic tube, torch, and inductor to evaluate heat losses and calculate the entire plasma system efficiency.

The main results of performed tests on Ar and air for both atmospheric and elevated up to 105 psig (~7 bar) pressures are reflected in Fig.3. The torch design demonstrated reliable remote ignition at 1+ bar pressure on any plasma gas including air.

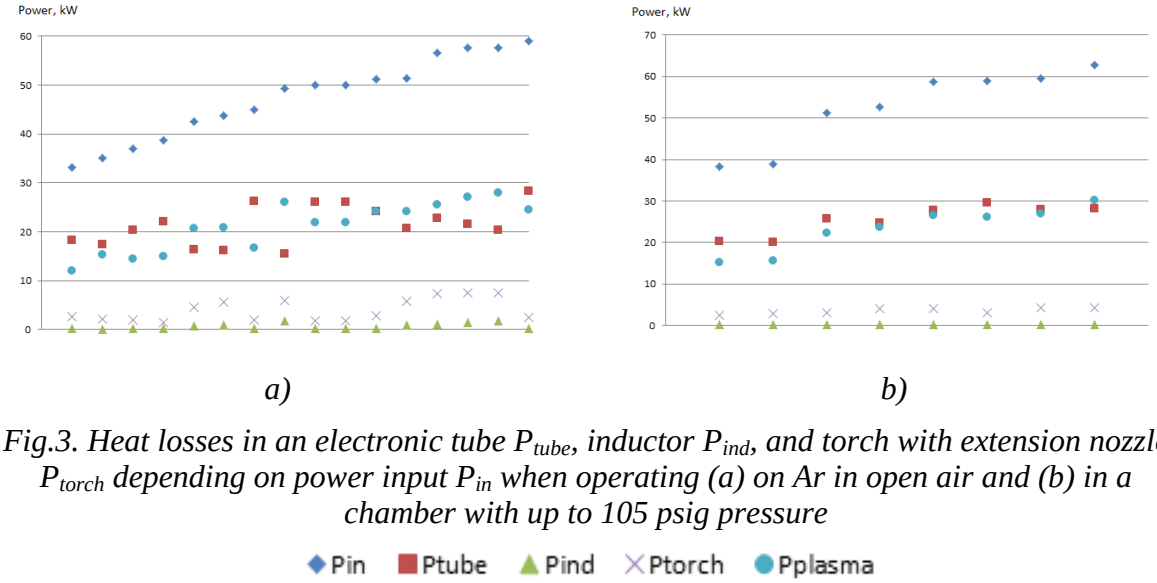

Fig.3. Heat losses in an electronic tube P_{tube}, inductor P_{ind}, and torch with extension nozzle P_{torch} depending on power input P_{in} when operating (a) on Ar in open air and (b) in a chamber with up to 105 psig pressure

Conclusions:

1. Developed for commercial application RF plasma system has demonstrated reliable remote plasma initiation and operation on Ar, air, and N_2 from atmospreric to 7 bar pressure with net power output from 14 to 30 kW in plasma.
2. Reverse vortex plasma stabilization provides higher torch efficiency in comparison to direct vortex and is more efficient particularly when operating on air as a plasma gas due to bigger plasmoid volume and its brightness.
3. Designed power supply allows stable plasma generation on variety of plasma gases at both atmosperic and elevated pressures at the plasma torch output, power regulation,

operation parameters control (plate voltage and current, grid current, input power, water flow through tube, torch, and inductor, water temperaturs for 4 points, etc).

4. Heat losses depend significantly on a plasma gas. In case of argon, losses in the inductor are 100-200W or almost nigligible, losses in the torch with extention nozzle are 1.5-3 kW or 5-7% of the input power, and in the tube 33-45%. In cases of insufficient compliance of load and power supply the tube losses could reach even 50%. When on air, heat losses in the inductor are 1 to 2 kW (3-5% of the input power), what is much higher than on argon mainly due to inductor heating up through the torch wall; losses in the torch with nozzle are 4 to 9 kW (10-16% of the input power) and increase could be explained by much bigger plasmoid volume and its brightness, and could be dramatically reduced by higher air flow; tube losses are 30-33% of the power input and less than on argon.

5. Total measured RF plasma system efficiency as ratio of the plasma plume output power and consumed from grid power was from 40% to 55%. It depends on many factors, mainly on: (a) compliance of power supply and load; (b) plasma gas composition and flow; (c) plasma stabilization scheme.

Multichannel Analyzers of Emission Spectra MAES

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Atomic emission spectrochemical analysis (AES) is currently one of the most informative methods of multielement analysis. It is widely used to control technological processes and products in various fields. As a source of excitation emission spectra of the substance in the plant are widely used various plasma sources: inductively coupled plasma (ICP), an electric arc, the flame of a gas burner, microwave plasma, glow discharge, the two-arc torch and other sources. Until the last quarter of the 1900s, the recording of the spectra of the plasma on photographic plates and by means of photomultiplier tubes was typical for AES. The use of solid-state detectors (SD), linear and array, for recording radiation made a real revolution in AES. It is not only that the execution time of analysis is shortened tenfold. The recording of spectra by solid-state detectors gave an opportunity to significantly reduce the detection limits of analytes, improve the accuracy of analysis, and correct effectively spectral overlaps.

Since the end of the last century, the VMK-Optoelektronika Company is working on the development and improvement of the linear multichannel analyzer of emission spectra (MAES) based on multicrystal assemblies of photodiode arrays [1]. MAES has been widely used in analytical laboratories in Russia and CIS countries; it is used with different excitation sources of radiation (DC arc and AC arc, spark, laser, inductively coupled plasma, arc plasma torch) and various spectroscopic instruments (prism and diffraction, domestic and foreign). In 2001, it was included in the State Register of Measuring Instruments of the Russian Federation, no. 21013-01. AES is continuously improved on the basis of the experience of its use in many analytical laboratories.

Basic photodiode array. To build hybrid assemblies, a basic array of photodiodes BLPP-369 is created with the photoelectric, geometric, and structural characteristics suitable for the recording of atomic emission spectra. The line contains 2612 photodiodes with 12.5 mm spacing, 1 mm in height, and 10^4 in dynamic range and is designed as a silicon crystal 33 mm in length. The length dimension of the photosensitive area to the edges of the crystal is 0.2 mm. In order to create multicrystal assemblies, the array contacts are located on one side of the crystal and are connected to the connectors of the circuit board by means of polyamide loops. Photodiodes BLPP-369 are sensitive to radiation in the range of 160–1100 nm.

Multichip assemblies of arrays. The methods are developed for constructing hybrid multichip assemblies of photodiode arrays, including the assemblies without the “dead” zones, which yielded large-scale linear detectors of optical radiation to equip a majority of spectral instruments used in AES. Open-frame chips bearing arrays with polyamide loops are placed on a single heat-stabilized substrate. The problem of stabilizing the photovoltaic parameters of the photodiodes and decreasing their threshold sensitivity is solved by reducing and stabilizing the temperature of the arrays with Peltier microcoolers. In this case, the effect of the drift of spectral lines on the results of the analysis is practically eliminated due to automatic correction of the temperature shift of the spectra by 2–3 reference lines per

assembly. The assemblies are manufactured in a sealed housing with a quartz input window filled with dry nitrogen at excessive pressure. The pressure and temperature sensors, as well as nonvolatile memory for storing information about the assembly (the type of crystals, their number, serial number, etc.) are installed inside the assemblies. The contacts of photodiodes in the array, located on the same side of the crystal, and the use of polyamide loop that enables a detachable connection with the printed circuit board allow the placement of the arrays over the spectral focal surface of different curvature, as well as in several rows.

The main types of multichip assemblies of linear detectors are shown in Fig. 1. Flat assemblies (Fig. 1a) are used in spectrographs with flat focal surfaces and one_dimensional dispersion. In the concave assemblies (Fig. 1b), the arrays are located along the lines approximating the arc, with lengths equal to the length of a single crystal. These assemblies are designed for using in quantometers with focal surfaces located on the Rowland circle and one_dimensional dispersion. Multiple assemblies (Fig. 1c) are designed to record spectra in spectrographs with crossed dispersion. The arrays are placed in several rows (lines), so as to ensure the recording of each of the spectral orders. In this case, the crystals are arranged in the direction of the dispersion of the grating. Options for docking crystal arrays in multichip assemblies are shown in Fig. 1d.

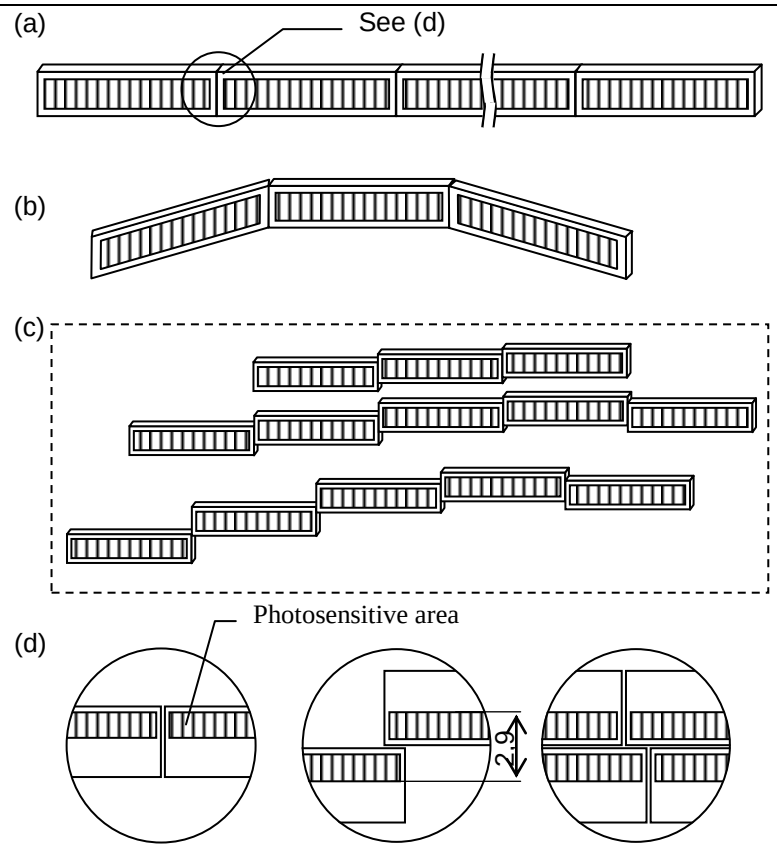

Fig.1. Main types of multichip assemblies: (a) flat, (b) concave, and (c) multiline and (d) options for docking crystal arrays (with a gap, without gaps, in two lines).

The radius of the mounting surface of crystals in the assemblies changes from concave +375 mm to convex –872 mm, and the number of crystals varies from 1 to 28. In addition, more than one assembly with a different number of crystals can be used for recording atomic emission spectra. For example, in the spectral instrument DFS-36, two 12-array and one 8-array assemblies are used. The length of the light_sensitive area of the assembly reaches 46 cm, and the number of photodiodes, 73 000.

Multichannel analyzer of emission spectra. MAES includes a multichip assembly, the unit of electronic recording, the power supply, and a computer. The image of the spectrum obtained at the output of the spectral instrument is formed on the photosensitive surface of the multichip assembly. Photodiode arrays in multi-chip assemblies record the spectrum simultaneously. Using a 16-bit ADC, the received signals are converted into digital values that are transmitted to a computer and processed further as a recorded

spectrum. MAES works under the "Atom" control software, operating in a Microsoft Windows XP/7 system. The intensity of spectral lines is measured in arbitrary units (%), which includes the integration of several photoresponses of photodiodes in the zone of the spectral line followed by the subtraction of the background intensity in the vicinity.

A version of rapid MAES is developed, yielding the recording of several thousand spectra with an exposure time about 1 ms during the excitation of radiation of the test sample. For example, in Fig. 2 shows the dependence of the intensity of the Au 267.595 from the time of arrival of the geological powder sample into the plasma. Exposure time of 0.5 ms. It is seen that flash of gold lines have a duration of about 1 ms.

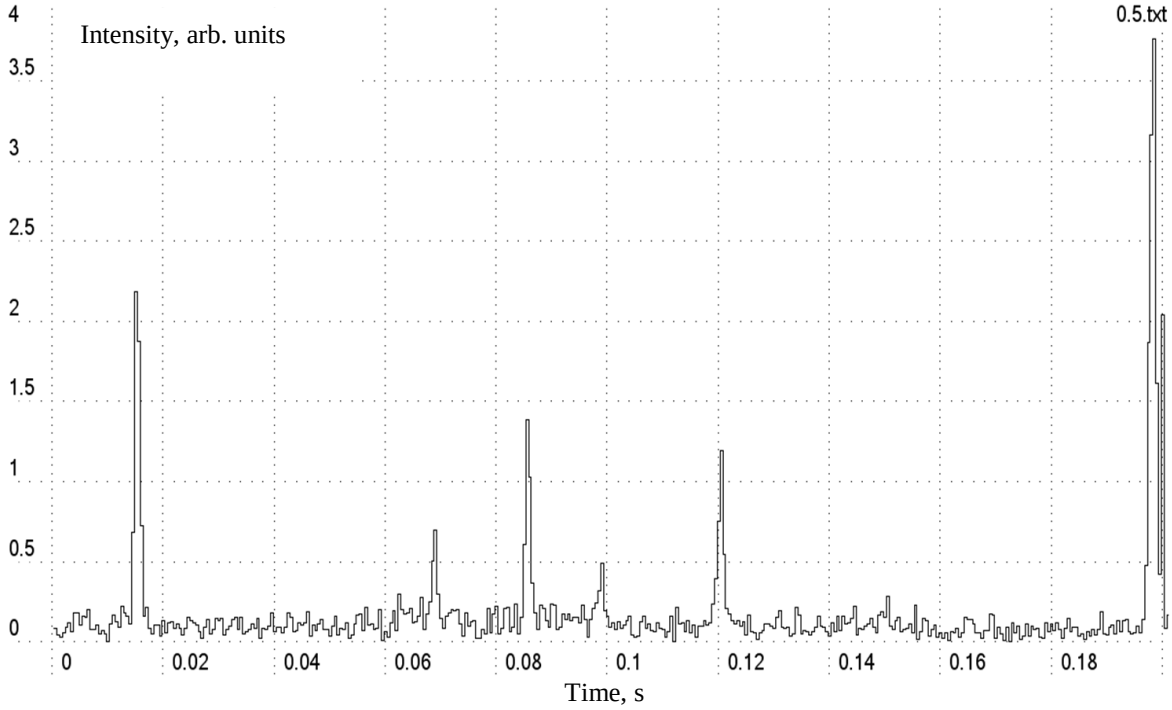

Fig.2. The dependence of the intensity of the Au 267.595 from time of receipt of the sample in the plasma

Spectrometers recording and processing MAES spectra. Spectrometers with MAES have been created on the basis of the available or new spectroscopic instruments. In the first case, MAES was mounted in the spectral instrument, available in the analytical laboratory, instead of the conventional system for recording spectra, based on photographic plates or photomultiplier, followed by a partial optimization of the optical system and instrument design. In the second case, the optical system of a multichannel spectrometer and a multichip assembly of the analyzer were designed in conjunction with full optimization of their characteristics.

In conclusion, note that the MAES analyzer has become a modern working instrument used in research, the development of new measurement techniques, and the performance of routine tests for emission spectral analysis in laboratories of research institutions and in the industry.

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Tandem Plasma Torch Development for Thermal Spray Production

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The development and the improvement of materials used in protective thermal coatings have a lot of applications in the aerospace and military industry. To study and develop this kind of material, the researchers of laboratory of plasmas and processes of the Technological Institute of Aeronautics (ITA), built a thermal plasma torch, called Tandem. The main purpose of the Tandem torch is to generate a plasma spray. Through this thermal spray is possible to spread metallic or ceramic powder (with high temperature and speed) about materials surface, where solidifies and forms a layer. This technique is versatile and little affects the surface of the base material.

The ceramic coating of a base material used as a thermal shield must to reduce the heat flow into the material re-radiating incident heat energy, thus ensuring a long life of the material when subjected to thermal cycles of high intensity, in addition to giving it a high tolerance voltages, low erosion rate and resistance to atmospheric reactive plasmas of oxygen and nitrogen in terrestrial environments reentry.

Fig. 1 shows the torch Tandem. This not transferred arc thermal plasma torch is operated with N_2, and can reach plasma jet temperatures in the range of 2000 to 3000 K with supersonic speed between 1200-1600 m/s. The torch has a mixing chamber made of graphite electrodes and is located between the two cooled copper electrodes. In this toch the thermal efficiency and average gas enthalpy surveying, was used the maximum power provided by the DC power source of 40 kW. Thermal efficiency measurements was performed varying the flow rate of N_2 gas from 5.5 to 7.5 g/s and the distance of the hot cathode from the torch center of 46, 56 and 61 mm.

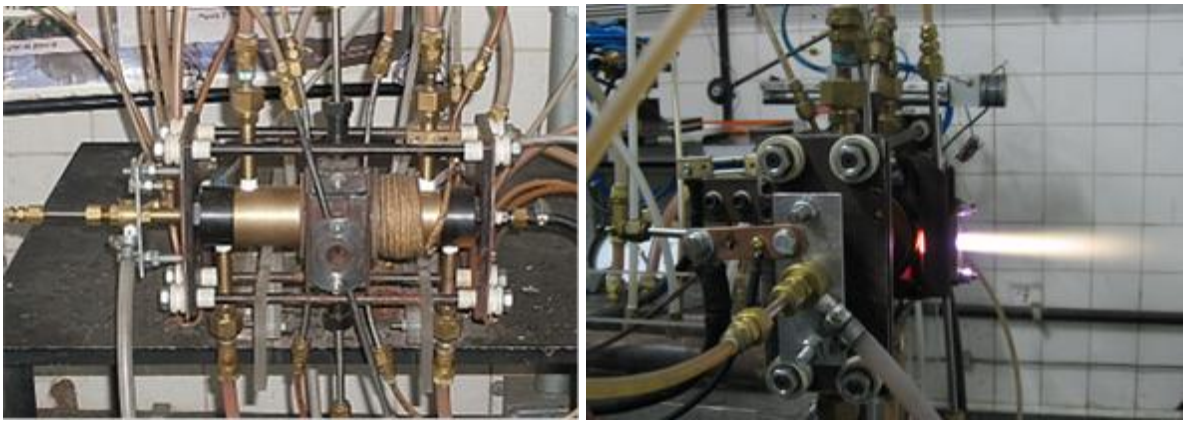

Fig.1. Frontal and size view of the Tandem torch developed in LPP/ ITA.

Fig. 2 shows the variation of the average gas enthalpy of the gas in function of the variation of gas flow and arc current at three distances from the cathode to the center of the torch. It can be seen that the higher the arc current, the more heat is transferred to the gas increasing its average enthalpy. With the gas flow increase, the lower the contact time for the heat transfer and the enthalpy decreases linearly. It can be seen that the torch operation is stable only above enthalpies of 4.6 [kJ/g].

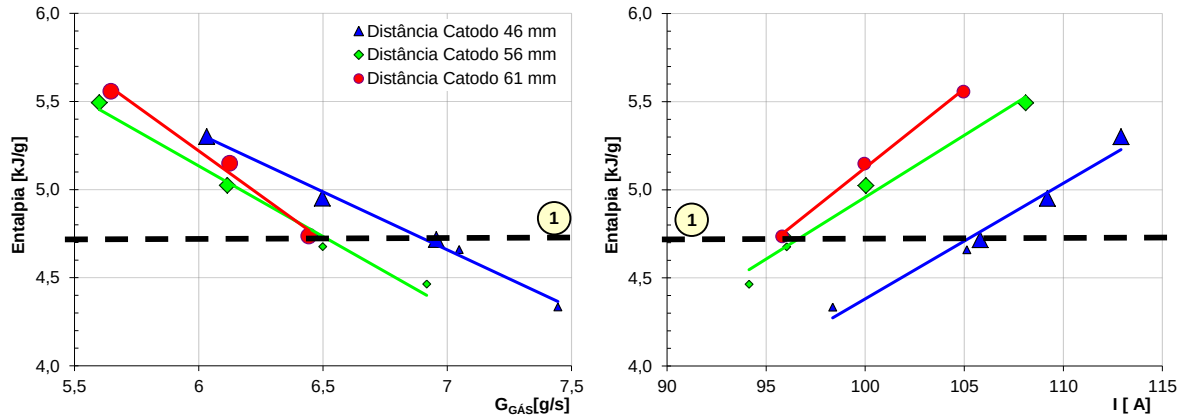

Fig.2. Variation of the average gas enthalpy as a function of the gas flow and arc current

Fig. 3 shows that the thermal efficiency declines linearly with the increasing of the current in the arc, because the higher the current, the narrower the arc heat channel, reducing the efficiency of heat transfer to the gas, yielding a maximum efficiency of 76%. The torch operation not shown stability for points of efficiency above 76% and currents smaller than 96 A.

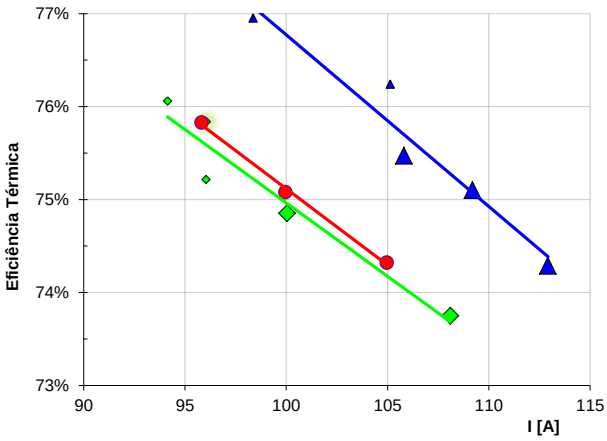

Fig.3. Thermal efficiency as a function of the operating current of the torch

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His research interests are concentrated in material sciences, applied plasma physics, mainly in thermal protective materials and thermal plasma torch operation, instrumentation and metrology.

High Power Combined Plasma Chemical Gasification and Combustion System for Contaminated Liquid Hydrocarbons Destruction

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A new combined gasification and combustion system based on especially designed combustor with plasma assisted pre-chamber has been developed for destruction of the contaminated liquid hydrocarbons, including used transformer oil. The project has accumulated results of the previous investigations referenced in [1]-[4]. An induction or radio-frequency (RF) plasma torch, developed by Applied Plasma Technologies, LLC, was selected as a plasma source to provide ignition reliability of liquids with high flash point and combustion stability of water contaminated fuels. Also, due to electrodeless design, the RF torch allows significant increase of the device life time in comparison with DC torches.

We following input data were accepted for modeling and design: (a) Transformer oil consumption - 100 liters per hour with temperature 300 K; (b) Plasma gas (air) flow rate - 2 grams per second; (c) Averaged plasma plume exit temperature - 5000 K.

For the three-dimensional modeling and calculations the program complex Ansys Fluent was used. A simplified two-stage kinetic scheme of the hydrocarbon $C_{16}H_{29}$ combustion, which imitates transformer oil and was applied for the analysis of a burn out process is as follows:

$$2C_{16}H_{29} + 30.5\ O_2 \rightarrow 32\ CO + 29H_2O;$$

$$2CO + O_2 \rightarrow 2CO_2.$$

It was supposed that transformer oil will be atomized by a number of centrifugal nozzles with air enhancement, located in various pre-chamber sections. During the variant calculations the optimal angle values of a nozzle installation relatively to a chamber axis and the fuel cone angles were obtained. For all investigated variants the drops distribution was accepted according to the Rozin-Rammler law - maximum drop diameter in a spraying spectrum was 75 micrometers, average 50 mcm, and minimal 5 mcm for the transformer oil physical properties as follows: density 890 kg/m^3, heat capacity 2,050 J/(kg·K), evaporation temperature 400 K, evaporation heat rate 200,000 J/kg, and boiling temperature 511 K.

Two basic schemes as a direct-flow and a counterflow were considered for investigations and further design. Due to performed 3-D modeling and calculations it was defined that the most reasonable solution is to split out the combustor on two zones – the first zone or pre-chamber with radial air swirler to provide better interaction of the axial plasma jet with atomized fuel to ensure complete fuel evaporation, partial combustion, and gasification; the second zone or the main combustor to provide complete combustion of initially evaporated and gasified feedstock.

The direct-flow scheme of the combustion chamber was considered firstly. Its design had two radial swirles and four radially installed on the pre-chamber wall nozzles. This scheme demonstrated insufficient combustion performance, mainly high CO emission reaching 20,000 ppm in the exit section at the output temperature 1020 K. The reasons were in overcooling of the combustion zone by cold air, insufficient evaporation of the atomized oil droplets due to their "sticking" to the pre-chamber wall, and weakness of the recirculation zone inside a flame tube.

The CFD modeling showed advantages of the counterflow chamber design as shown in Fig. 1 with a radial swirler in pre-chamber, axial swirler at the main chamber fuel end, and a reverse vortex swirler at the exit end. Further numerical experiments allowed optimize the pre-chamber geometry, fuel injection angle, air access coefficient for both combustion zones, air distribution ratios between the swirlers, and achieve minimal emissions.

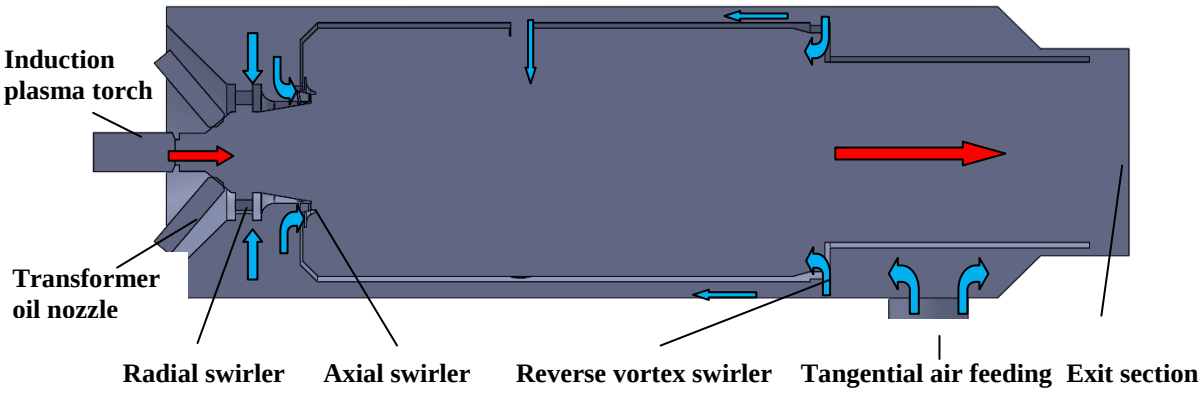

Fig.1. Scheme of the counterflow combustion chamber

Typical for the final design temperature and flow velocity distribution is shown in Fig.2.

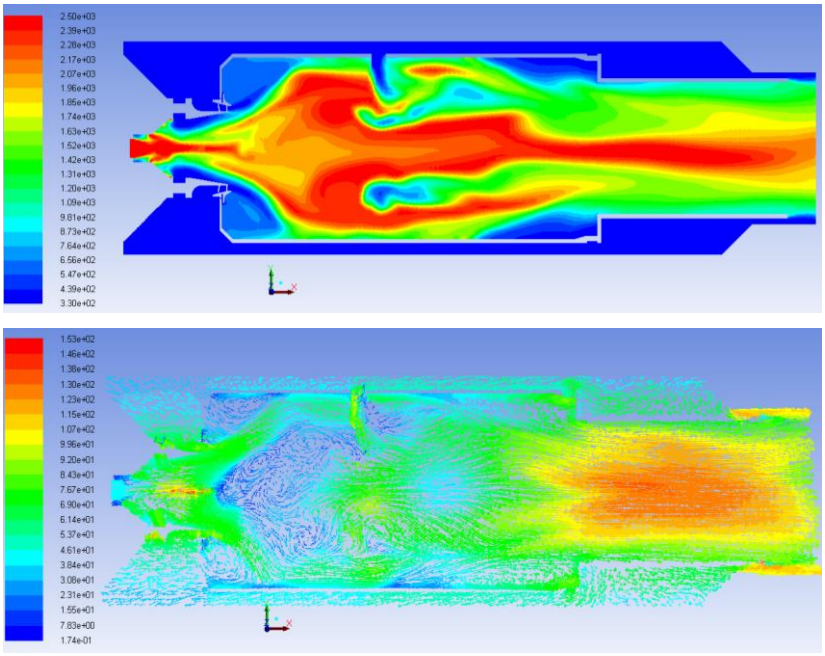

Fig.2. Temperature contours (K) and velocity vectors (m/s) within the combustion chamber

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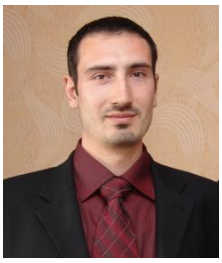

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Preliminary Study of Product Gas Reformation Using Plasma Torch

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Introduction

The aim of this study is to minimize the tar in product gas. To reach this, we present preliminary calculations including mass balance and enthalpy change in order to calculate the plasma temperature in the reform.

Preliminary calculations

The thermal plasma used was the non-transferred DC plasma torch. The working gas was nitrogen.

The system operation is given as follows. The product gas from biomass gasification was reformed in the plasma torch, which is inserted in the throat of a Venturi tube.

Mass balance on the Venturi:

$$\dot{m}_p + \dot{m}_g = \dot{m}_r \tag{1}$$

where $\dot{m}_p$ is plasma mass flow [kg/h], $\dot{m}_g$ is product gas mass flow [kg/h] and $\dot{m}_r$ is gas reformed mass flow [kg/h].

The plasma gas enthalpy was calculated according to [1].

The enthalpy change on the Venturi:

$$\Delta H_p + \Delta H_g = \Delta H_r \tag{2}$$

where ΔH_p is the plasma enthalpy change [kJ/h], $\Delta H_g$is the gasification gas enthalpy change [kJ/h] and ΔH_r is the reform enthalpy change [kJ/h].

Results

The Reynolds number of the product gas was 2237 and the pressure drop due to the Venturi was 14 Pa. Therefore, the product gas flow is between laminar and turbulent regimes, and the pressure drop on the Venturi is insignificant.

Table 1 shows the results of mass balance and enthalpy change whereas Table 2 shows the temperature values of the reform according to the product gas flow and H_2/CO ratio estimated for reformed gas.

Table 1. Parameter and value for mass balance and enthalpy change

Parameter	Value	Unit
$\dot{m}_g$	11	kg/h
$\dot{m}_p$	48	kg/h
$\dot{m}_r$	59	kg/h
ΔH_g	9804	kJ/h
ΔH_p	222962	kJ/h
ΔH_r	232766	kJ/h

Table 2. Temperature according to the gasification flow and H_2/CO ratio

Gasification flow (Nm^3/h)	H_2/CO	Reformed gas temperature (K)
10	1	2293
	2	2027
14	1	2223
	2	1966
18	1	2159
	2	1911
22	1	2099
	2	1859

Conclusion

The temperature calculated at the outlet of the Venturi throat (reformed gas temperature) presents high enough to crack the tar in product gas (1859-2293 K). In this study, the demonstrated results were based on preliminary choices of the involved parameters. Therefore, the parameters presented here show the possibility of achieving tar reduction in product gas.

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Conducts research related to co-gasification of biomass and industrial waste for energy generation. Has experience in production engineering and implemented industry PPCP for metallurgical industry. Worked with managing production teams in the automotive industry.

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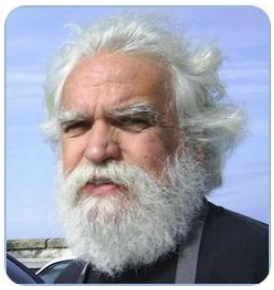

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Hydrocarbon Reforming in CO_2 Thermal Plasma

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An increased utilization of fossil fuel has caused the atmospheric accumulation of carbon dioxide, which induces significant climatic changes. Conversion of CO_2 into more valuable chemicals is a very attractive idea and a number of researches worldwide have been performed. The plasma-assisted methods developed for reducing CO_2 emission are: RF plasma; corona; dielectric barrier discharge; glow discharge; gliding arc and thermal plasma.

Carbon dioxide can be decomposed by itself or by reacting with H_2, C, CH_4 and higher hydrocarbons under high temperature conditions. This high temperature can be obtained by using thermal plasma as well as non equilibrium plasma. The difference between these two methods consists in how the electric energy is delivered to the reacting substances. For plasmas in thermal equilibrium the most of supplied electrical energy is transformed into translation motion of particles and only small part intended for excitation, dissociation, ionization, etc. In the case of non-equilibrium plasmas the principal part of electrical energy is converted into excitation of vibrational levels of molecules.

Simultaneously with direct reaction $CO_2 \rightarrow CO + 1/2O_2$, with $\Delta H = 2.9\text{eV/molecule}$, a reverse reaction of CO_2 formation is also occurring. Thus, the thermal dissociation process must include two phases – heating and fast quenching to stabilize the reaction products from reverse reactions. Taking into account the data of the reversibility and equilibrium of the reaction it is possible to obtain conditions for increased yield of CO_2 decomposition.

The quenching is the principal factor, which determines the component distribution of final product. Moreover, the final product distribution depends on the rates of competing reactions during the quenching. Thus, the control of the quenching temperature is very important for the thermal plasma processing. The quenching is not effective if the quenching rate is less than 10^5 K/s [1]. The developed quenching chamber consists of a system of refrigerated discs, equipped with a flow turbulizer. Estimated quenching rates are up to 10^7-10^8 K/s. The experimental setup fulfill principal requirements of plasma chemical reactors: ability to work for a long time under high temperature conditions and with elevated thermal efficiency; assure a uniform distribution of temperature and reagent densities in the reaction zone; guarantee an adequate residence time of the reforming/synthesis products and provide the required conditions for product quenching.

Fig.1. Experimental system. Plasma torch (1) acopled with quenching chamber (2)

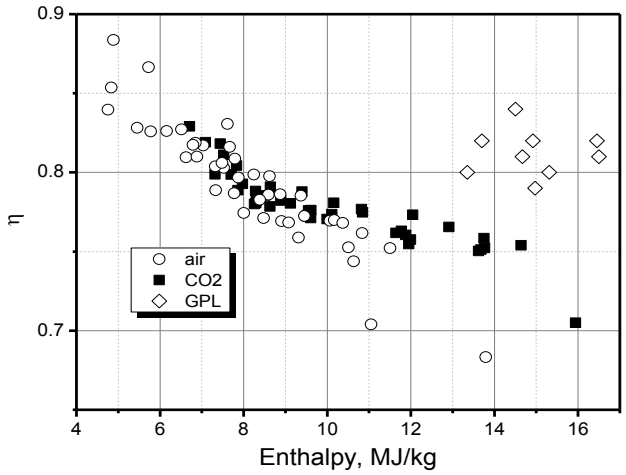

Fig.2: Thermal efficiency of plasma torch η versus plasma jet enthalpy for different plasma forming gases

A plasma chemical reactor, based on DC plasma torch (described in [2]), was attached to the quenching chamber (Fig. 1). A reverse vortex of plasma torch diminishes thermal losses and increases discharge power per unit of arc length that gives rise to high temperature in arc column and high enthalpy of the plasma. Plasma torch thermal efficiency versus enthalpy of plasma jet is presented in Fig. 2. For working regimes a thermal efficiency of plasma torch was 80-85%.

In this work more attention was paid to reforming of GPL[1] mixture with CO_2 in proportion 1:4. Thermodynamic equilibrium composition of the mixture is shown in Fig 3. Calculations were made considering the following species: H, H_2, O_2, O, OH, HO_2, H_2O, H_2O_2, CO_2, CO, CH_2, CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_6, C_3H_8, C_4H_6, C_4H_8, C_4H_{10}, C_5H_{12}. The temperature varied from 300 K to 6000 K.

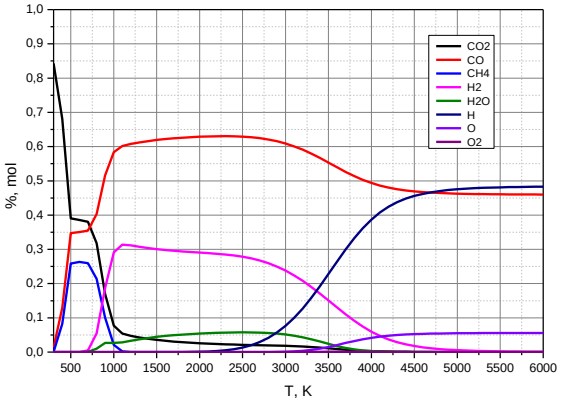

Fig.3. Reforming CO_2 with GPL. Composition of outlet gases in thermodynamics equilibrium

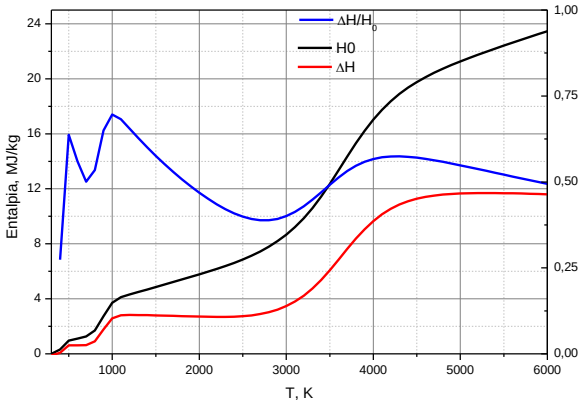

Fig.4. Enthalpy of mixture CO_2 and GPL

Fig. 3 shows that a range of temperature from 1000 K to 3000 K is suitable for formation of CO and H_2. Favorable conditions for methane formation are at temperatures below 1000K, when practically all hydrogen was consumed. The composition of output gas at T=1100 K is: H_2 – 31%; CO – 60%; CO_2 – 5,4% e H_2O – 2,8%. The enthalpy of the mixture is shown in Fig. 4. Here H_0 is total enthalpy and $\Delta H = H_0 - \int_{T_0}^{T} c_p dT$ ΔH is reforming enthalpy. From thermodynamic point of view the best reforming temperature is 1000K when 70% of the thermal energy ($\Delta H / H_0$) is spent to reforming and only 30% for heating of the reaction mixture (see Fig.4). Another favorable regime is nearly 4100 K (57% for reforming).

[1] Liquefied petroleum gas, also called LPG, GPL, LP Gas

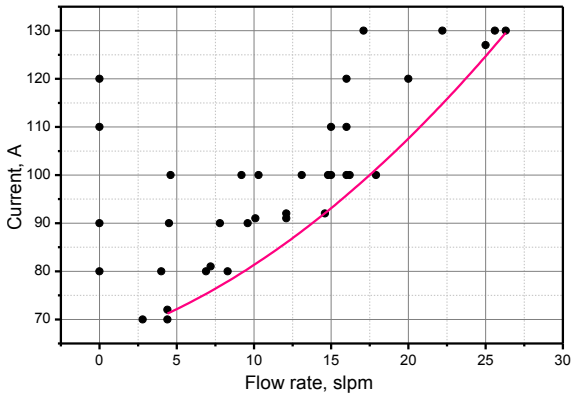

Fig.5. Plasma torch operation limits. Flow-rate of CO2 60 slpm

Table 1. Principal components of reforming and energy characteristic E_e of the process

	CO, %	H_2, %	CO_2, %	E_e, kJ/mol
1	36,74	28,67	8,75	338
2	36,25	30,86	6,90	358
3	32,44	11,38	36,93	852
4	32,72	11,45	36,29	753
5	70,55	17,78	6,49	354
6	75,63	18,39	5,87	392
7	59,83	8,75	25,94	620
8	61,06	10,24	26,39	549

Fig. 5 shows the operating limits of the plasma torch in coordinates "arc current" – "flow rate of LPG." An increase in LPG flow rate (with constant flow rate of CO_2) causes instabilities and shutdown of the plasma torch. The red line shows the limits of torch operation. It is clearly observed that an increase of the energy supplied to the mixture (by increasing the arc current) increases the amount of LPG to be reformed in the reactor without the arc extinction.

Design of full factorial experiments was performed to maximize the energy efficiency of the plasma chemical reactor. Two principal factors were taken into account: LPG flow rate G_{LPG} and arc current I. Flow rate of CO_2 in all experiments was 60 slpm. The enthalpy of plasma jet was from 14.5 MJ/kg to 16.5 MJ/kg, which corresponds the bulk temperature of 3700-3900 K. Outlet gas composition and energy efficiency of the process $E_e = \eta IU / (G_{CO_2} + G_{LPG})$ are shown in Table 1. The result of factorial experiments shows that in order to diminish the energy expenses it is necessary to increase LPG flow rate and reduce the arc current.

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Study of Syngas Production from Tar Reforming by Microwave Plasma Torch at Atmospheric Pressure

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Now a day, scientific community is searching for new fuels able to replace fossil fuels with economic and environment gains and biofuel play a relevant rule, mainly for the transport sector. A major process to obtaining such type of renewable resource is biomass gasification. This process has as product a gas mixture containing CO, CH_4, and H_2 which is named synthesis gas (syngas). However, high molecular organic species denominated tar are also produced in this process [1]. As tar is an undesirable contaminant [2], it must be removed through a gas cleaning process, which reduces significantly its gas heating value. One way for tar removing without reducing the gas containing energy is tar reforming using microwave plasma torch. In this case, all gas coming from the gasifier is used to generate a plasma torch and tar is mainly converted into CO and H_2.

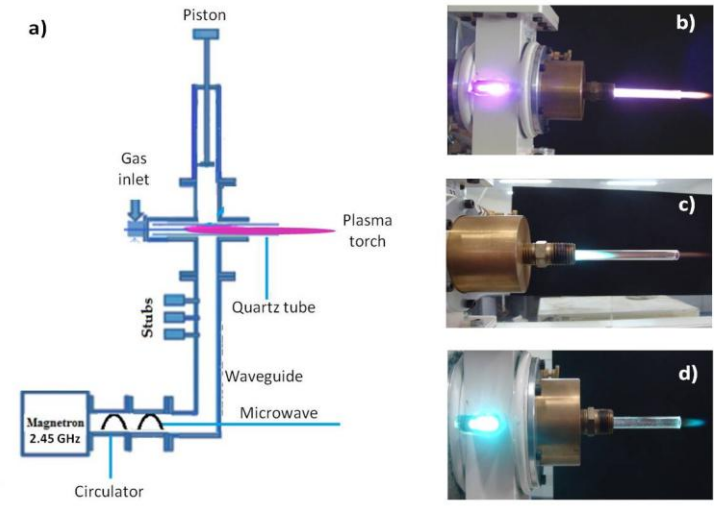

Fig.1. a) Schematic diagram of the microwave plasma apparatus Photography of the plasma torch: b) Ar plasma, c) (Ar + ethanol+ H_2O) plasma, and d) (Ar + tar solution) plasma

In this study, a 2.45 GHz microwave plasma apparatus (MPA) at atmospheric pressure was used to investigate the syngas production from tar reforming. The MPA consists a 0-3 kW magnetron power supply, a circulator, a water cooled matched load and applicator. The applicator includes a tuning section, which is required to reduce the reflected power, and a quartz tube. A variety of gases have been used to produce the plasma torch including argon, H_2O vapor, ethanol vapor, and vapor of tar solution. These inlet gases were heated up to ~350 °C in order to keep its constituents in gas phase. Constant tar concentration solution comprises commercial tar (30% vol.) diluted in mixture of ethanol + H_2O (70% vol.). The magnetron power supply was kept at 1 kW and the argon (Ar) flow rate at 1296 L/h. The mixture of ethanol and H_2O flow rate was kept at 15 mL/h and the tar solution flow rate was varied from 6 to 15 mL/h. Fig. 1(a) shows a schematic diagram of the system used in this work. Fig. 1 (b-d) shows photography of Ar, mixture of Ar + ethanol + H_2O and mixture of Ar + tar solution plasma torch, respectively.

The optical analysis was performed with an optical emission spectrometer (Ocean Optics - model USB4000) operating in the range of ultraviolet and visible. Fig. 2 (a-b) shows the optical spectrum of the mixture Ar + ethanol + H_2O plasma, and mixture Ar + tar solution plasma, respectively. Comparing the Fig. 2(a) and 2(b), it is observed an increasing in the neutral carbon (CI-247.83 nm) which was deposited on the wall of the quartz tube. The

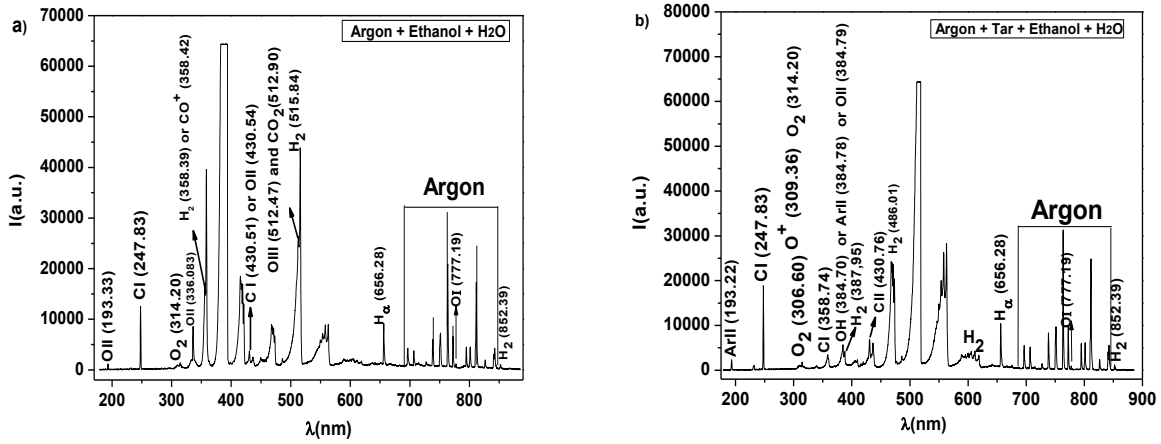

Fig.2. Optical spectrum of the microwave plasma torch: a) Ar + ethanol + H_2O plasma, with the mixture of ethanol + H_2O flow rate at 15 ml/h, and b) Ar + tar solution plasma, with tar solution flow rate at 15 ml/h

formation of the ionized carbon (CII-430.76 nm), which may form the CO molecules (it was also verified in the Fig 2(b)). The CO species was detected in both spectrums (467.71, 469.15, and 558.11 nm). The hydrogen specie (H_2) at 600 nm, and atomic oxygen at 777.19 nm, are only observed in the Fig. 2(b) which are, probably, from the tar reform [3], [4].

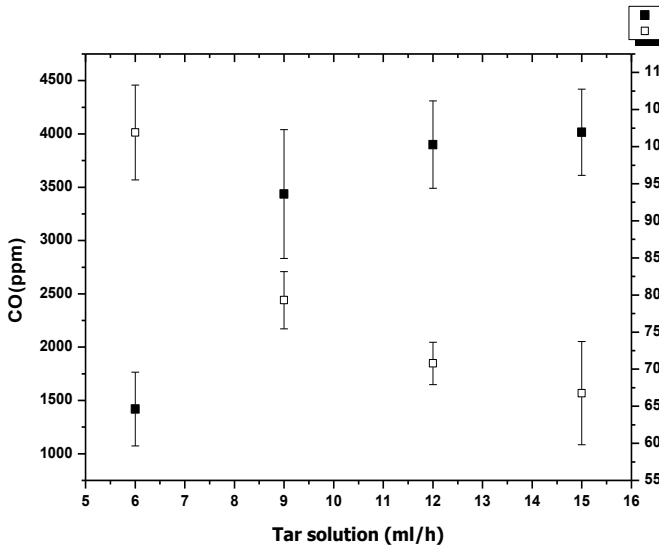

Fig.3. CO and O_2 concentration as a function of the tar solution flow rate

The GreenLine GL8000 gas analyzer was used to determine the CO and O_2 concentrations in gases downstream reactor and result is showed in the Fig. 3 as function of the tar solution flow rate. It is observed a reduction on the O_2 concentration with an increasing on tar solution flow rate as well as an increasing on CO concentration. Due to the

measurement on CO mol fraction and H2 presence indication, it is possible to conclude that the MPA is a promising technique for tar reforming into syngas.

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Particle Trapped Vortex Reactor with Meridional Counter Flow Gasdynamics for Plasma Assisted and Combustion Processes

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An air-fuel vortex reactor with the swirl-induced global meridional circulation is developed. The meridional circulation together with the circumferential rotation of air creates a uniform volume-distributed heat and mass transfer. There are two sources of the hot gases generation was considered. First source is the combustion/oxidation of the fuel and second source is the plasma generated hot gases. Balance between the aerodynamic and centrifugal forces creates the stratifications of the high and low temperature gases. Due to higher density the low temperature gases moves to the side wall and hot gases accumulates near the central line of the reactor. In both cases the hot temperature zone always confide in the central region of the reactor. The plasma or combustion products never touch the walls. The reactor wall temperature is very low such that does not require any means for the walls cooling or defending wall material from oxidation by the plasma or hot combustion products. This effect reduces the material requirements for the reactor and increase service time before the reactor material failure.

The solid or liquid particles, introduced into the vortex reactor, follow the trajectory of the gas inside the reactor. Global meridional circulation transfers the particle along the sidewall from the exhaust to the intake dead end of the reactor, where they makes U-turn and moves now along the center line of the reactor. They fly some distances near the center line away from the intake dead end toward the exhaust. Shifted by gravity and turbulence from center to the side they became affected by increasing centrifugal force and go to the wall. Near the wall the global meridional circulation transfer the particle again to the dead end. The vortex reactor serves as the trap for the particles. No one particle can leave the reactor until it completes the reaction. The particle residence time in the reactor is approaching to the infinity. High relative velocities between particle and gas provide high heat and mass transfer. Vortex reactor with freely flying particles through the different temperature and velocity fields has no famous drawbacks which the fluidized bed reactors have.

Analytical approach is developed to model the global meridional counter-flow in a cylindrical vortex reactor where a tangential inflow of a fluid induces both swirl and the meridional circulation. The flow goes from the inlet near the sidewall to the dead end, where it makes U-turn and goes back in the central region to the exhaust. For the counter-flow to develop, the flow must have enough swirl momentum, the tangential inlet must be located at the right place, and exhaust orifice should have a determined diameter.

For high swirl, the experiments and simulations reveal a new important paradoxical feature: the development of the double counter-flow. In this case, the flow goes from the inlet near the sidewall and from exhaust near the center to the dead end, where it makes U-turn and goes back in the annular region to the exhaust. The wild turbulence (typical for large Reynolds number flows) does not destroy the counter-flow and even the double counter-flow. These paradoxical features are due to a special self-developed pressure distribution at high swirl. A physical mechanism of these counter-and double-counter flow is discovered and explained.

The favorable flow patterns and features are first were discovered in the experiments, than verified in analytical and numerical simulations of the turbulent reacting flows with the help of STAR-CCM+ CFD software.

The combustion experiments with kerosene and propane confirm the favorable flow patterns and reveal new important features such as the bottle-like and umbrella-like combustion patterns, transparent ultra-lean combustion of propane and blue-color volume-distributed oxidation of kerosene with single-digit ppm emission of CO and NOx.

The favorable flow patterns and features allow using the vortex reactor in many applications, e.g., it can be used as the nuclear reactor with pelleted fuel. Vortex reactor can be used for biofuel production, for gasification and burning the coal.

Combustion experiments, analytical solution and CFD simulations

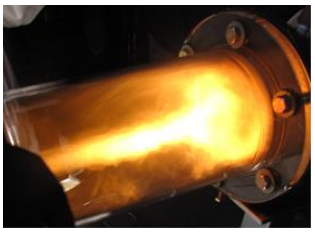

Fig.1. Combustion of 1.6 g/s kerosene at the air mass rates 36 g/s with umbrella-like combustion zone. One can see spiral tracks of liquid fuel from left to the right

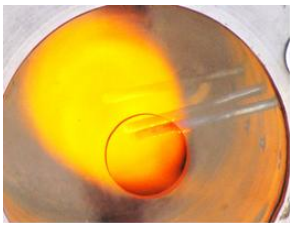

Fig.2. Bottle-like combustion of kerosene. Red color of the thermocouple's rods show high temperature zone in the center of the combustor; dark color – low temperature of gas and walls

Fig.3. Double counter flow at combustion of propane (0.5 g/s propane, air mass rate 38.5 g/s)

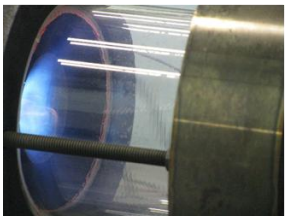

Fig.4. Transparent, blue reaction zone of kerosene combustion for lean mixture

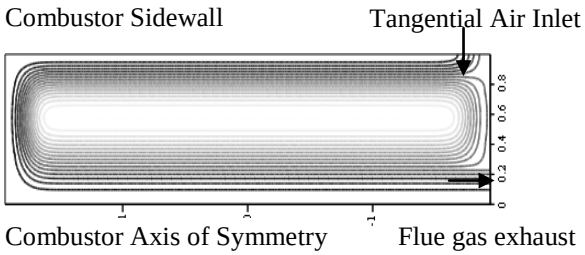

Fig.5. Global meridional circulation and flow through the combustor. Analytical solution

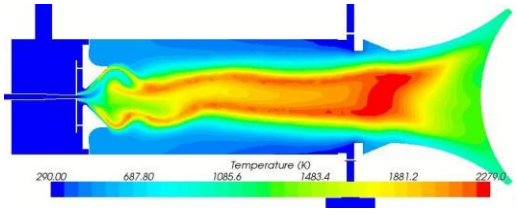

Fig.6. Temperature distribution in the vortex combustor. CFD simulation of the propane combustion

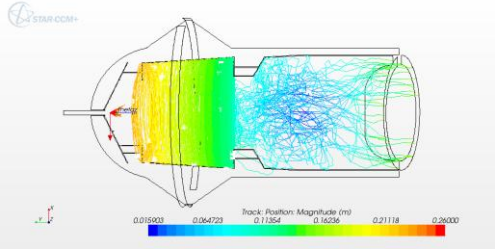

Fig.7. Particle tracks position magnitude from CFD simulations

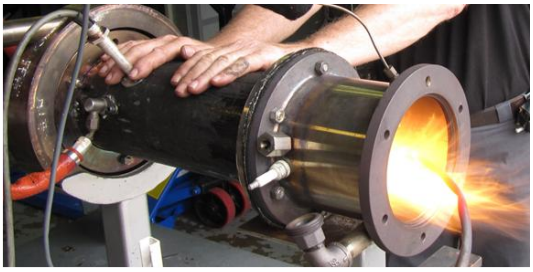

Fig.8. Cold wall combustor. Compare CFD simulations temperature distribution on Fig.6

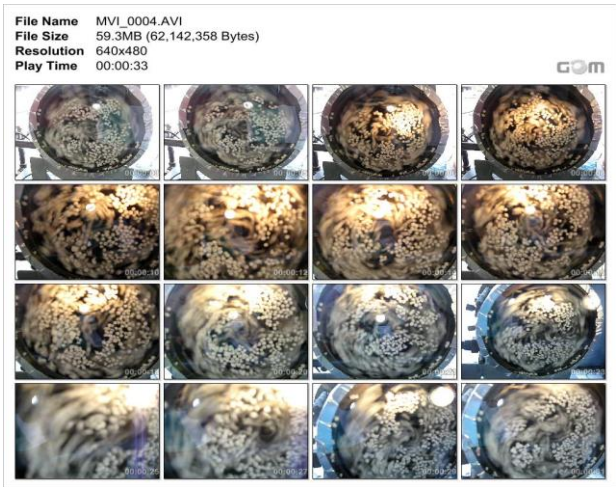

Fig.9. Snap pictures of particle trajectories near the particle trapped vortex reactor dead end in every 2 second

Dr. Anatoli A. Borissov *is the President and CEO for General Vortex Energy Inc., in Houston. He was the Principal Investigator for the NAVY grant "High Efficiency Fuel Cell System for Shipboard Applications" for Phase I and Phase II and the Principal Investigator for NAVY Phase I and Phase II contract on "Flameless Oxidation/Combustion". He holds four US Patents. His recent invention protected by US Patent 6,708,905 involving the supersonic injection of gaseous fuel, have greatly increased fuel efficiency (>10%) in large-bore gas engines while simultaneously reducing NOx emissions by 95%. He is the author of the experimental discovery in physics: "Rarefaction shock waves near thermodynamic critical point". Prior to coming to the USA as the Fulbright Professor in 1993, he served as the Head of the Department of Applied Hydrodynamics and supervised 85 scientists involved in solving a number of tasks associated with the combustion, noise, drag reduction and detection utilizing the internal waves in the ocean. Dr. Borissov is a world recognized expert in combustion processes, heat transfer and gas dynamics. He is the author of the book "Dynamic Structure of Detonation in Gaseous and Dispersed Media", 1991 @ Kluwer Academic Publishers.*

Dr. Borissov has authored many significant papers published in the American Institute of Aeronautics and Astronautics, Annual Review of Fluid Mechanics, Physics of Fluids, Journal of Fluid Mechanics, International Journal of Heat and Mass Transfer, and International Journal of Energy for a Clean Environment.

He is an active member of ASME, corresponding member of Russian Academy of Natural Science and ERCOFTAC. He was the Chairman of the Session on 13 International Conference on Dynamic Explosion and Reactive Systems (ICDERS), Nagoya, Japan 1991.

Dr. Borissov currently is working on the development of multi-fuel vortex combustors for turbine applications and energy conversion systems.

Comparisons between Global and 2-D Fluid Model Results of a Low Pressure Inductively Coupled Oxygen Plasma

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The plasma technology has been contributing to the improvement of electronics to the manufacturing of microelectronic devices, microelectromechanical systems (MEMS) and development of new materials [1]. Since oxygen discharges have been applied to plasma processing, the need for numerical models that describe oxygen chemical reactions requires further studies in this area.

In this work, a numerical approach was adopted for the study of oxygen inductively coupled plasma reactor at low pressure by means of a global (volume-averaged) model programmed in MATLAB® (which is the method previously adopted by [1], [2]) and a model developed on COMSOL Multiphysics® for analysis of a two-dimensional domain. A set of chemical reactions with respective reaction rates was mounted for O_2 plasma considering the data presented in the literature. By these methods, results such as electron temperature, density of species and electronegativity are obtained, and they are compared with those available in the literature. It was investigated the dependence of these quantities as a function of gas pressure, mass flow rate and discharge power.

Fig. 1 shows the dependence between electron temperature and electron density as a function of pressure as calculated by the global model for a cylindrical reactor (radius is 15 cm and length is 30 cm) when 100 W is absorbed by the system. The flow rate is 50 sccm and the gas temperature is 600 K.

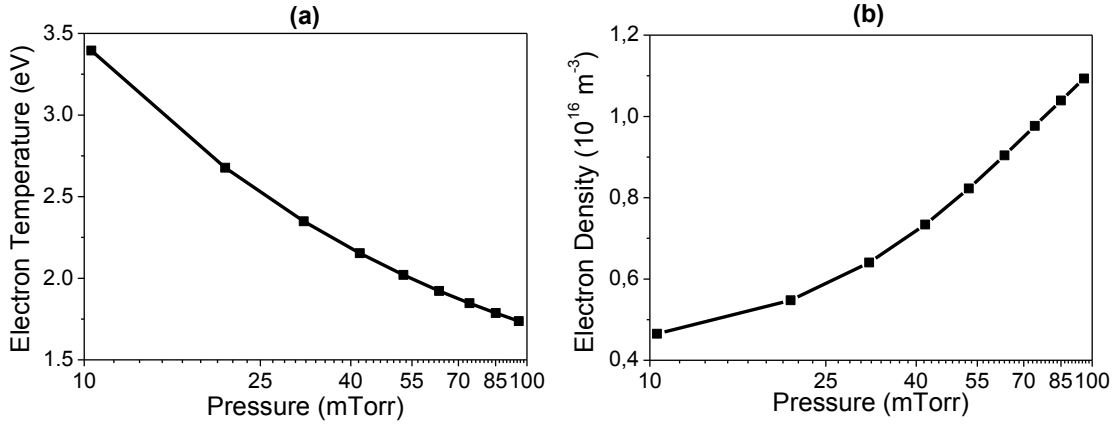

Fig.1. Results, as a function of pressure (100 W absorbed), of global model for electron: (a) temperature; (b) density

The results shown in Fig. 1 will be compared with those obtained from the Multiphysics

model, which will be presented at ICPAT 2013.

In Fig. 2 we also show the results when the pressure is fixed at 50 mTorr and the power absorbed by the system is changed.

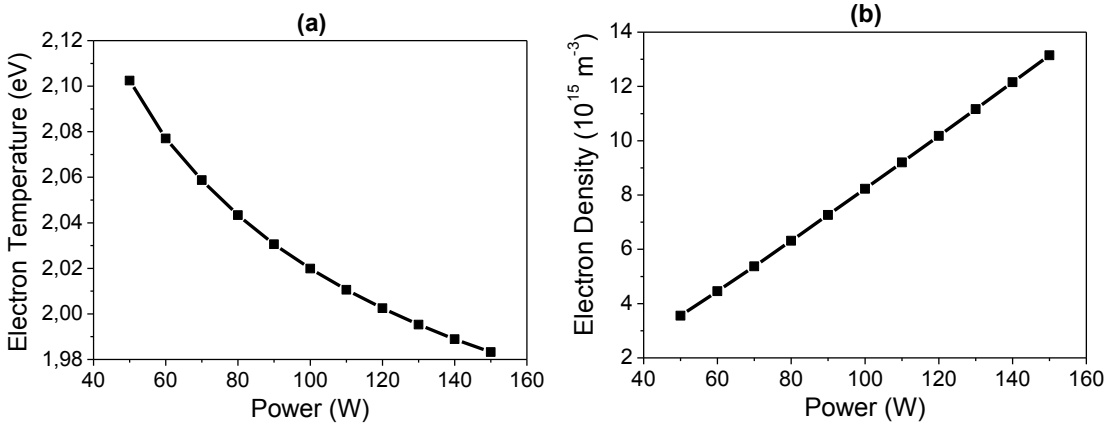

Fig.2. Results, as a function of power (50 mTorr), of global model for electron: (a) temperature; (b) density

Although Fig. 2 shows a decrease in the electron temperature when the power is increased, it is worth noting that the dependence between these two is not significant, which corroborates the behaviour previously observed by [3]. The global model is being improved to include a set with more chemical reactions.

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Electron Energy Distribution Function Control in Inhomogeneous Non-Stationary Plasma for Practical Applications

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Introduction

To predict the main scenarios of plasma behavior in different gas discharge devices aimed for practical applications require detailed information on rate constants of elementary processes in a gas inside these devices under an influence of external electric field, which can be controlled of programmed.

This information can be achieved with a help of solution of Boltzmann equation for electron distribution function (EDF) in which included information on gas characteristics (sort of a gas, typical temperatures, behavior character of the electric field in the device, ionization level, and cross sections of electron-molecule elementary processes.

In order to predict main scenarios of electron distribution function (EDF) control of electron distribution function (EDF) control, first of all it is necessary to develop a kind of roadmap of formation a different modes of the EDF in the inhomogeneous unsteady plasma. This analysis shows that the time scales are determined by the ratio between the transient time (the characteristic time of electron transport through the plasma volume τ_L) and the relaxation times of the EDF momentum τ_m (on velocity direction) and the relaxation times of the EDF energy τ_ε. Accordingly, for the spatial variable it is the ratio between the characteristic size of plasma *L* and an electron mean free path λ (momentum relaxation) and a length of energy relaxation of electron energy λ_ε. A significant difference between the scale of momentum relaxation and energy $\tau_\varepsilon >> \tau_m$, $\lambda_\varepsilon >> \lambda$ (reaching two or more orders of magnitude), allows to predict the possible modes of the EDF formation, with various degrees of selectivity effects on different groups of electrons (from a local EDF when it is possible to affect only the entire ensemble of electrons) and the nonlocal EDF, when different groups of electrons behave independently of each other and it is possible to influence only on the interest groups of electrons. Obtained information about EDF allows determining necessary information on rate constants of elementary processes in the definite device.

Methane-air mixture. On a basis of this approach we have considered gas discharge parameters of methane-air mixture , where it is necessary to determine rate constants of ionization and attachment. Data on cross sections in methane was taken from [1]-[3]. In Fig.1-2 one can see results of our calculations for direct ionization and attachment coefficients in methane-air mixture at different percentage of methane. Using these data and approach of [4] we obtained effective ionization frequencies in air-methane mixture in constant electric field. At that breakdown fields characterized by E/N parameter (E-electric

field strength value, N-gas density) when the avalanche ionization starts to realize at T=300 K are represented in Table 1.

Table 1. Breakdown values of air-methane mixture at methane percentage 0-40%, E/N, $\cdot 10^{-17}$, $V \cdot cm^2$. Torr Breakdown values of methane-air mixture, E/N, $\cdot 10^{-17}$, $V \cdot cm^2$

Constant field, T=300 K	P=20 Torr	P=76 Torr	P=760 Torr
4% methane	120	120	120
9,5% methane	121	121	121
20% methane	122	122	122

Considered approach allows make correct predictions on conditions in plasma, its ionization level, main ions and other use full characteristics. Variation of effective ionization field, which can be realized in plasma can determine choice of one or another power source, or change temperature or pressure characteristics in definite devices.

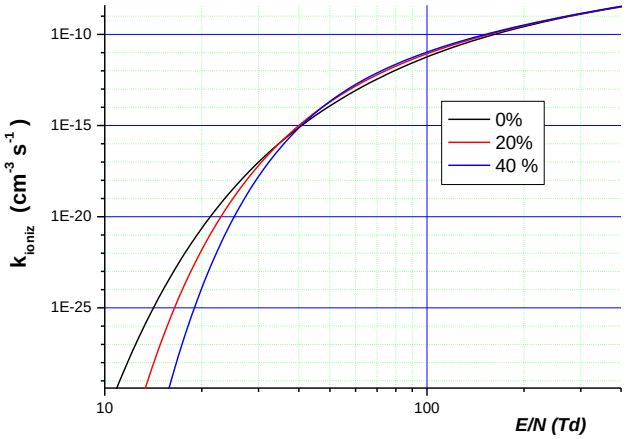

Fig.1. Direct ionization coefficient dependence via E/N in methane-air mixture at different percentage of methane

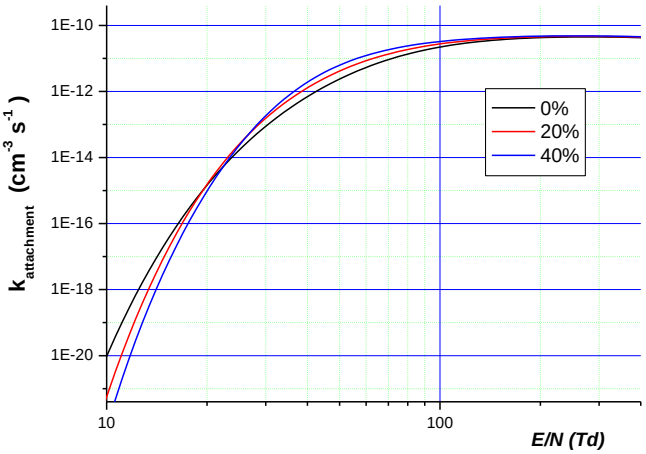

Fig.2. Dissociative attachment $e + O_2 \rightarrow O^- + O$ coefficient dependence via E/N in methane-air mixture at different percentage of methane

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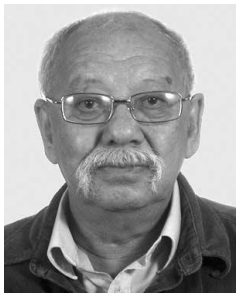

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On Kinetics of Pulsed Discharge in Humid Air

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Data on humid air discharge parameters is actual problem connected with experiments with discharge realization in real conditions, in layers over human body, skin and wounds, in ecology, etc. So before realization of experiments it is convenient to undertake investigations of humid air plasmas. However there is no available information on plasma in humid air and its comparison with plasma in dry air what is connected with a complexity of its ion composition. So the goal of this work is development of approach to analysis of humid air plasmas. For analysis of pulsed discharge over water surface we applied our program for non-self-maintained discharge in air developed in [1]. It contains air chemistry and electron-molecule reactions in external electric field in air taken from [2], [3]. Main rate constants of plasma chemical reactions are analogous to those of [3], [4]. In conditions of experiments with discharges over a water surface it is necessary to consider the humid air over a surface of water where concentration of water molecules in a layer over water surface contains about 0.05-2% of water molecules.

Undertaken analysis of available literature and methods for modeling of reactions has shown that the plasmas in humid air at this stage of modeling includes only water molecules in the gas phase without large aerosol particles. At the modeling we use reactions with participation of following reagents: positive ions O^+, O_2^+, O_4^+, H^+,H_2^+, OH^+, HO_2^+, H_2O^+, $O_2^+(H_2O)$, H_3O^+, $H_3O^+(H_2O)$, $H_3O^+(OH)$, $H_3O^+(H_2O)_2$, $H^+(H_2O)_2$, $H^+(H_2O)_3$, $H^+(H_2O)_4$ negative ions O^-, O_2^-, O_3^-, H^-, OH^-, atoms O and H, molecules H_2, O_2, H_2O, O_3, free radicals OH, HO_2, H_2O_2, excited states $O(^1D_1)$, $O(^1S_0)$, $O_2(^1\Delta_g)$ electrons and molecular species including nitrogen from the system of reactions developed by us for dry air, the estimate number of all reactions (including those for dry air) is 280-300. We also considered reactions of ion recombination of each positive ion with each negative ion, and rate constants for these reactions were estimated, since these reactions are not investigated yet for all ion combinations. We accounted the plasma electron cooling due to elastic collisions with water, oxygen and nitrogen molecules, and excitation of their vibrational and rotational levels of freedom. At that it is supposed that de-excitation of vibrational and rotational levels takes place mainly during the collisions with molecules. The corresponding heating and cooling terms for the electron energy equations are to be interpolated with respect to electron temperature T_e. The model includes reactions of three-body attachment to the molecule O_2 at presence of H_2O as the third body, charge – exchange and ion-ion recombination with all the positive ions.

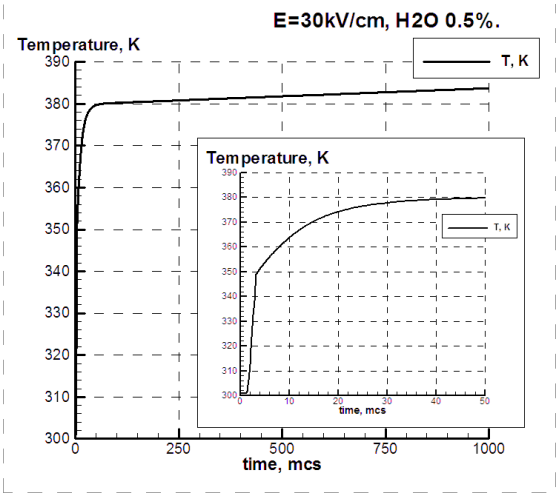

Fig. 1a

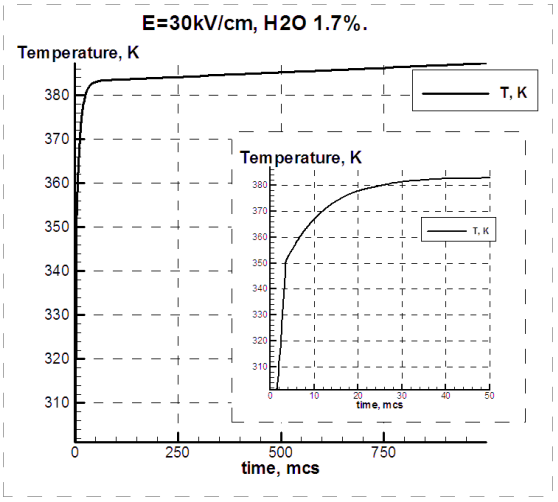

Fig. 1b

In Fig.1 a, b we represent calculation results for a discharge heating of air-water mixture in time with 0.5 and 1.7 % H_2O at height of about 0.85 mm and 0.1 mm over water surface (at external breakdown field 30 kV/cm).

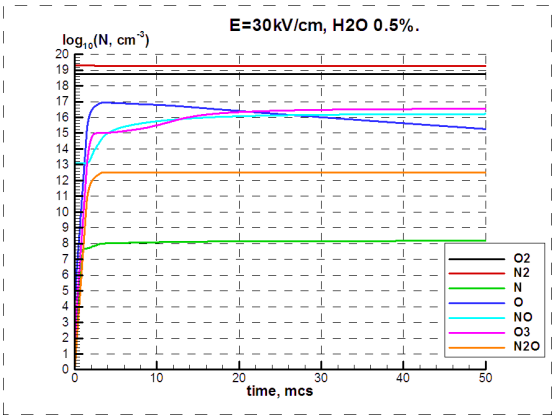

Fig. 2a

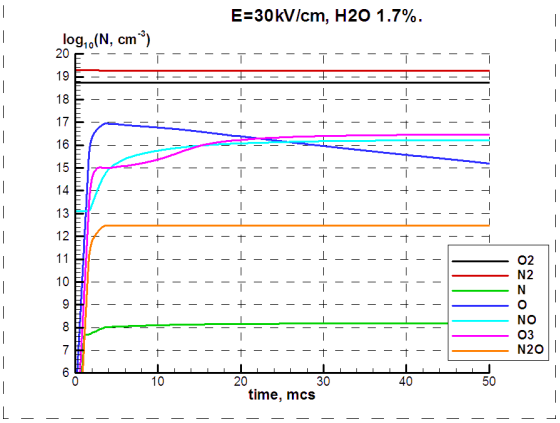

Fig. 2b

In Fig.2 a, b we represent calculation results for a discharge production of main neutral components in air-water mixture with 0.5 and 1.7 % H_2O at height of about 0.85 mm and 0.1 mm over water surface (at external breakdown field 30 kV/cm).

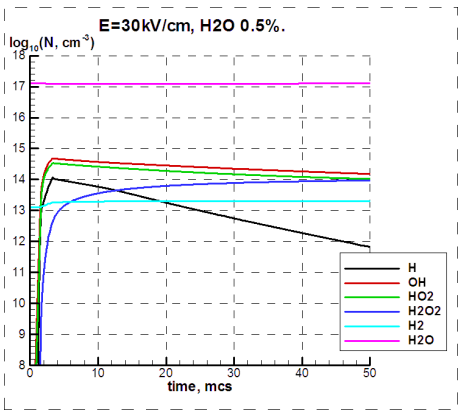

Fig. 3a

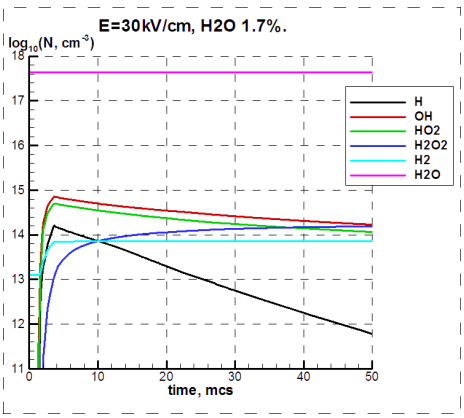

Fig. 3b

In Fig.3 a, b we represent calculation results for a discharge production of OH components in air-water mixture with 0.5 and 1.7 % H_2O at height of about 0.85 mm and 0.1 mm over water surface (at external breakdown field 30 kV/cm).

Calculations show that during a pulse of the discharge of ~20 μs takes place heating of air for ~75 K, by this time O_3 becomes one of the main components of the plasma, what makes this water-air mixture plasma convenient for sterilization applications.

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Vladimir L. Bychkov *has 40 years of experience in plasma physics researches, namely, in physics of elementary processes, gas discharges, electron-beam plasmas, plasma chemistry and ball lightning. Dr. Vladimir L. Bychkov had undergraduate studies in University of Friendship (Moscow) and post graduate studies in Moscow Power Institute and got Ph.D., in Plasma Physics and Chemistry. He got Dr. of Sciences degree in Molecular physics and Thermal physics. He conducts his scientific researches as leading scientist in M.V. Lomonosov Moscow State University and as head of plasma chemistry laboratory of MRTI. He is head of Russian committee on Ball lightning and vice-president of International committee on Ball lightning.*

Igor V. Kochetov *graduated from Department of Radiotechnics and Cybernetics of Moscow Institute of Physics and Technology (MIPT) in 1974, and received Ph.D. degree in radio physics from MIPT in 1977. In 1978, he joined Special Design Bureau "Almaz", Moscow. In 1981 he joined Branch of Kurchatov Nuclear Energy Institute (now State Research Center of Russian Federation "Troitsk Institute for Innovation and Fusion Research"), Troitsk, Moscow region. Since 1993 he is leading researcher. His research focused on the development of theoretical and numerical modeling of electron, ion, molecular vibration, and chemical kinetics in no thermal plasmas. He has contributed to theory of the vibrational kinetics; methods of calculation of the electron rate coefficients in gases under non-uniform, non-stationary field and electron density conditions; theory of the negative differential conductivity under different conditions; the kinetics of the CO_2 and CO lasers; the kinetics of excimer and ionic excimer lasers; the plasma ionization instabilities and spatio-temporal evolution of gas discharge during constriction of its plasma column. Currently he is doing simulation of singlet delta oxygen production in an electric discharge and plasma ignition of combustion in a supersonic flow. He received the Award of Government of the Russian Federation in 1998.*

On Kinetics of Pulsed Discharge in Water Vapor

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Data on discharge parameters in water vapor is actual problem connected with experiments with discharge realization over surfaces of different liquids, in ecology of water purification, etc. So for realization of experiments it is convenient to undertake investigations of water vapor plasmas. However there is so far no available information on plasma in water vapor with information about its composition what is connected with a complexity of plasma chemical processes in it. So the goal of this work is development of approach to analysis of water vapor plasmas. For analysis of pulsed discharge over water surface we applied our program for non-self-maintained discharge in humid air developed in [1]. It contains air chemistry and electron-molecule reactions in external electric field in air taken from [2], [3]. Main rate constants of plasma chemical reactions are analogous to those of [3], [4]. In conditions of experiments with discharges in water vapor it is necessary to consider the water vapor with where concentration of water molecules in a layer over water surface contains about 0.4 - 2% of air molecules.

Undertaken analysis of available literature and methods for modeling of reactions has shown that the plasmas in humid air at this stage of modeling includes only water molecules in the gas phase without large aerosol particles. At the modeling we use reactions with participation of following reagents: positive ions O^+, O_2^+, O_4^+, H^+,H_2^+, OH^+, HO_2^+, H_2O^+, $O_2^+(H_2O)$, H_3O^+, $H_3O^+(H_2O)$, $H_3O^+(OH)$, $H_3O^+(H_2O)_2$, $H^+(H_2O)_2$, $H^+(H_2O)_3$, $H^+(H_2O)_4$ negative ions O^-, O_2^-, O_3^-, H^-, OH^-, atoms O and H, molecules H_2, O_2, H_2O, O_3, free radicals OH, HO_2, H_2O_2, excited states $O(^1D_1)$, $O(^1S_0)$, $O_2(^1\Delta_g)$ electrons and molecular species including nitrogen from the system of reactions developed by us for air, the estimate number of all reactions (including those for dry air) is 280-300. We also considered reactions of ion recombination of each positive ion with each negative ion, and rate constants for these reactions were estimated, since these reactions are not investigated yet for all ion combinations. In the model we account the plasma electron cooling due to elastic collisions with water, oxygen and nitrogen molecules, and excitation of their vibrational and rotational levels of freedom. At that it is supposed that de-excitation of vibrational and rotational levels takes place mainly during the collisions with molecules. The corresponding heating and cooling terms for the electron energy equations are to be interpolated with respect to electron temperature T_e. The model includes reactions of charge – exchange and ion-ion recombination with all the positive ions.

In Fig. 1 we represent experimental and calculation results from [5] where there was considered electron density decay in the H_2O vapor high – voltage nanosecond discharge

afterglow for 2.5 Torr. For modeling we considered ionization and decay in model conditions: 2.5 Torr H_2O vapor (where rate constants and parameters were taken from solution of Boltzmann equation for water vapor discharge), air 0.01 Torr, gas temperature T=300 K. These conditions can differ from parameters of high-voltage nanosecond discharge plasma created in [5]. Namely we determined that maximum concentration in the first pulse will be equal to the experimental one $N_e = 1.5 \cdot 10^{12}$ cm^{-3} at the electric field strength value 4.085 kV/cm and its duration 20 ns. After 0.3 μs as in the experiment we repeated the pulse equal to the first one. We obtained the same results as in the experiment and theory during the first pulse decay, see Fig. 2 and Fig. 3. However the second pulse in our case led to much higher electron concentrations. This effect we attribute to difference of excitation by the discharge parameters used by us and realized in [5]. During the first decay positive ions H_2O+, H_3O^+, $H^+(H_2O)_2$ and $H^+(H_2O)_2$ control decay of electrons, during the second one - H_2O+, H_3O^+ ions.

So we have developed a code describing humid air plasma created by the electric discharge and made calculations for conditions close to those of experiments [6]. Generally speaking we obtained satisfactory agreement between experimental and computed results for the considered case.

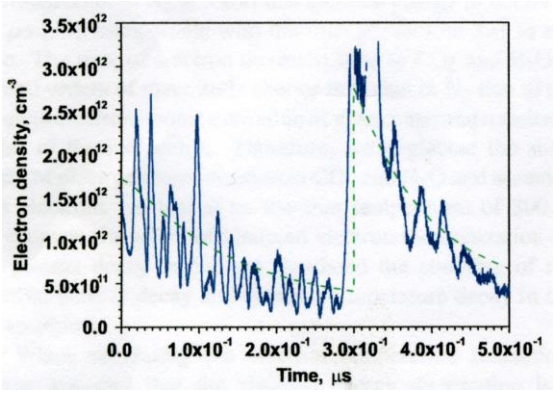

Fig.1. Electron concentration decay after pulses of a high-voltage nanosecond discharge [5]. Solid curve –experimental measurements. Dashed curve –theory

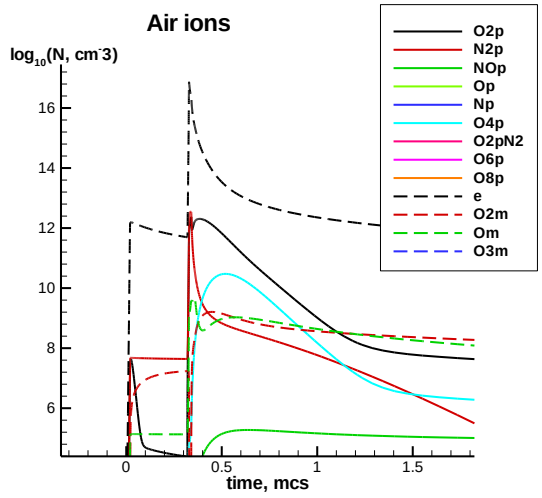

Fig.2 Electron and ion concentration decay after pulses of a high-voltage electric field, electric field value is 4.085 kV/cm and its duration 20 ns, water vapor 2.5 Torr

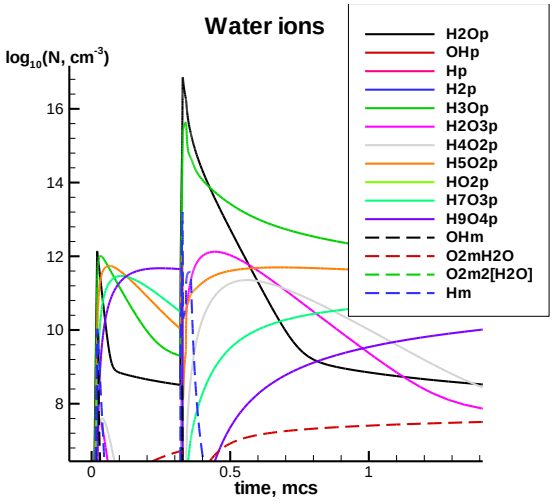

Fig.3. Water ion concentration decay after pulses of a high-voltage electric field, electric field value 4.085 kV/cm and its duration 20 ns, water vapor 2.5 Torr

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Plasma Processing of Carbonaceous Raw Material

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This paper presents the results of long-term studies of plasma-chemical technologies of pyrolysis, hydrogenation thermochemical preparation for combustion, gasification and complex processing of solid fuels and cracking of hydrocarbon gases [1], [2]. The application of these technologies to produce desired products (hydrogen, carbon, hydrocarbon gases, synthesis gas, valuable components of the mineral mass of coal (MMC)) meets modern ecological and economic requirements of the power industry, metallurgy and chemical industry.

Technologies of plasma conversion of carbonaceous materials (coal, petroleum coke, hydrocarbon gases) are characterized by high levels of temperature and, therefore, a high degree of their thermochemical conversion to desired products. Plasmochemical technology of cracking is to heat hydrocarbon gases in the combined electric arc reactor to a temperature of pyrolysis (1900-2300 K) with the formation of fine carbon and hydrogen in unified technological process. Plasmochemical hydrogenation of solid fuels, which is the pyrolysis of coal in a hydrogen atmosphere, provides acetylene and other unsaturated hydrocarbons (ethylene C_2H_4, propylene, C_3H_6, C_2H_6 ethane, etc.) from cheap low-rank coals by their treatment with hydrogen plasma. Plasmochemical hydrogenation of coal is a new process of direct production of acetylene and alkenes in the gas phase, in contrast to conventional hydrogenation (liquefaction) of coal. As a result of experiments on low-rank coal hydrogenation in plasmochemical reactor at its power of 50 kW, coal consumption of 3 kg/h, and propane-butane mixture flow of 150 l/h gas of the following composition is obtained, mass %: C_2H_6=50, C_2H_2=30, C_2H_4=10.

Plasma ignition of coal is based on plasmochemical preparation of fuels for combustion, which results in the formation highly reactive two-component fuel (fuel gas and coke residue) from low-rank coal. Highly reactive two-component fuel is formed already at T = 900-1200 K, which allows the process at relatively low specific power consumption (0.05-0.4 kWh/kg of coal) and leverage at TPP for oil-free boiler start-up and pulverized flame stabilization. Plasma gasification and complex processing of coal to produce synthesis gas and valuable components from MMC were investigated using universal experimental setup. From an environmental point of view, these technologies are most promising. Their essence is heating of coal dust by the arc plasma, which is oxidant, to complete gasification temperature at which the coal organic matter is transformed into an environmentally friendly fuel - synthesis gas free of ash particles, nitrogen oxides and sulfur oxides. At complex processing of coal simultaneously with gasification of organic matter in the same reaction volume coke carbon restores MMC oxides and valuable components, such as industrial silicon, ferrosilicon, aluminum and carbosilicon and microelements of rare metals: uranium, molybdenum, vanadium, and others, are formed.

Experiments on plasma pyrolysis (cracking) of propane-butane gas mixture were performed in plasmochemical reactor of 100 kW nominal power. In the experiments, propane-butane mixture flow amounted to 300 l/min, and the plasma reactor power was 60 kW. During the experiments hydrogen and carbon (soot) were obtained. Physico-chemical analysis of the soot samples has shown that it is a different nanocarbon structures mainly in the form of "colossal" nanotubes with high electrical conductivity and mechanical strength.

Table 1 summarizes the results of investigations of carbonaceous raw plasma conversion.

Table 1. The optimal range of process parameters for plasma conversion of carbonaceous raw

Fuel / plasma forming gas	***T*, K**	**Specific power consumption, kW·h/kg of fuel**	**Fuel conversion degree, %**	**Concentration, mg/Nm^3**	
				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. Plasmochemical hydrogenation of coal (hydrogen)					
10	2800–3200	6.5–8	70–100	0	0
5. Plasmochemical cracking of propane-butane mixture					
18 m^3/ч	1500–2500	2.2–3.8	98–100	0	0

At complex processing of coal conversion of the mineral mass requires high temperatures (2200-3100 K), which leads to higher specific energy consumption up to 2-4 kW h/kg. Thus the high degree of carbon conversion (90-100 %) is achieved. Plasma-steam gasification provides a transition to the gas phase mainly organic mass of coal that does not require such high temperatures, as in the complex processing, and enables process at relatively low specific power consumption (0.5-1.5 kW h/kg) and achieving a high degree of conversion (90-100%). Plasma-chemical hydrogenation of coal requires high temperatures (2800-3200 K), which leads to high specific power consumption for the process (6.5-8 kW h/kg), which allows achieving high conversion (70-100 %) for direct (one-step) receipt of acetylene and alkenes in the gas phase. To ensure a high degree of conversion (98-100%) of hydrocarbon gas in the combined plasmochemical reactor there is no need in such a high temperature. That allows carring the process at relatively low specific power consumption (2.2-3.8 kW h/kg). Note that all the processes of plasmochemical processing of fuels (Table 1) are characterized by extremely low concentrations of nitrogen oxides and sulfur emissions not exceeding 20 mg/Nm^3, which is much lower than when conventional use of fuels.

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Double Atmospheric Pressure Cold Plasma Jet Divergence in Air

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The generation and applications of cold plasma atmospheric pressure plasmas attracted many researchers to explore for new sources of cold plasmas [1]-[4]. Therefore, we introduce in this work a double atmospheric pressure cold plasma jet system. It is single electrode He double AC cold plasma jet in air. The system is consisted of a cylindrical alumina (Al_2O_3) insulator tube with outer diameter of 4.5 mm and 80 mm length. The tube has two capillaries of the same hole diameter (1.5 mm) and their centers are spared by 2 mm. AC sinusoidal voltage was applied to a cupper ring single electrode surrounded the alumina tube. The electrode is located at 2 cm for the tube nozzle. The peak to peak current values increased from 6 mA to 12 mA as the applied voltage increased from 7 kV to 17 kV. The current voltage wave form indicts that the generated plasma jet is homogenous plasma. The spectroscopic rotational temperature measurements of the jet indicate that the jet has a temperature near to room temperature. As well as, the generated plasma can be touched safely. The plasma jets showed a diverging behavior by increasing the applied voltage at constant low value of flow rate or by decreasing the flow rate at constant value of applied voltage. Moreover, the jets length increases with increasing the flow rate or the applied voltage then it saturate with an incline to decrease again at higher flow rate values. These results indicate that this system can be used for plasma surface modifications for large area treatments.

Acknowledgment

This work was supported by the National Science, Technology and Innovation Plan (NSTIP) through the Science and Technology Unit (STU) at Taibah University, Al Madinah Al Munawwarah, KSA, with the grant number 08-BIO24-5.

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Professor Jae Koo Lee

To Combustion Nature of Discharge Created Fireballs

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Questions of natural fire balls -the ball lightning (BL) – the long-lived shining object in atmosphere are without the certain answer more than for a century. Experimental modeling of the given phenomenon was carried out in different laboratories. Owing to absence of unequivocal model and complexity of experimental modeling of the given object an interest to BL as perspective for researches and applications object has sharply fallen.

However, in experiments [1]-[3] in discharge tubes and erosive discharges long-lived objects of the small size (up to 1 cm) and a lifetime in some seconds both of organic, and the inorganic nature have been obtained.

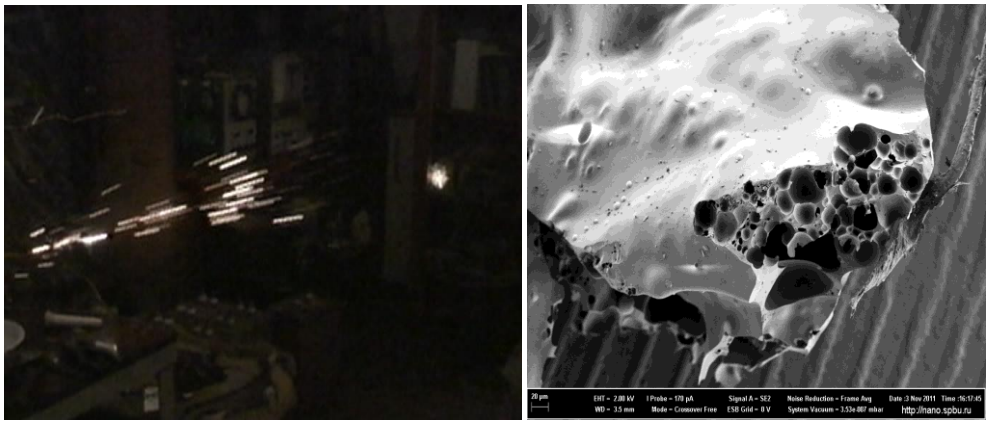

Fig.1. a) An object explosion event. b) The object surface [2]

Analysis of residuals of the fireball [2] created on a basis of basalt structure has lead to a conclusion that the object appearance was connected with complex processes of its formation and combustion.

Fig.2. a) An object appearance event. b) The object surface [3]

In [3] in the erosive discharge with inserts of organic materials shining objects with the visible size up to 2 cm and a life time up to 2 seconds have been obtained. The analysis of its residuals has lead to a conclusion that the object appearance was connected with complex processes of its formation and combustion.

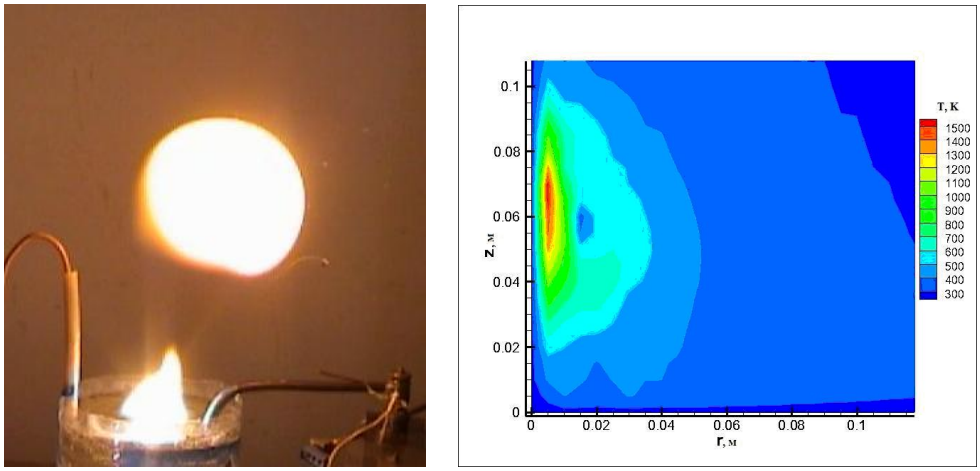

Fig.3. Gatchina discharge: a –principle scheme: a) An image of the luminescent object; b) Temperature distribution in the formed toroidal vorte a) t=0.005 s; b) t=0.07 s. [6]

In, the so-called, Gatchina discharge [4], [5], the electric discharge is realized at an energy put between two electrodes, one of which is at the bottom of a vessel, and the second electrode-over a surface of a liquid with which the given vessel is filled. As a result of processes of energy put in, its part, in a form of plasma, is released over the upper electrode, and then over it the luminescent sphere of radius up to 6 cm floats, it exists from milliseconds to shares of seconds. In [4] it was supposed, that the sphere represents an object with temperature below 500 ^{0}C, however the optical measurements [5] have shown, that the gas temperature in the sphere can reach 1700 ^{0}C as a result of the chemical reactions (combustion) which are taking place at a stage of discharge realization. Our recent investigations [6] have shown that a vorticle structure appears when a hot gas of a temperature ~1700 K is delivered to an area modeling a tube electrode. So it also verifies a combustion nature of the realized object.

All these experiments and analysis of [7]-[10] results give grounds to suppose that natural long lived luminous objects called ball lightning have a mutual nature connected with plasma combustion.

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Research of Short Atmospheric Pressure DC Glow Microdischarge in Air

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New type of gas discharges-microdischarges are of interest in solution of different problems of material processing and medicine. Our work is devoted to investigation of this discharge type.

Experimental and simulation results of short (without positive column) atmospheric pressure dc glow discharge in air are presented. We used metal steel electrodes with a gap of 1-100 microns. The experimental voltage-current characteristic's (VAC) have a constant or slightly increasing form at a small gap. The most stable microdischarges were burning at application of a flat cathode and rounded anode, when the length of the discharge is automatically established near the minimum of the Paschen curve [1] by changing their binding on the anode. In this case microdischarge was stable and it had growing VAC. For simulations we used 2D fluid model with kinetic description of electrons. We solved the balance equations for vibrationally- and electronically-excited states of nitrogen and oxygen molecules; nitrogen and oxygen atoms; ozone molecule; and different nitrogen and oxygen ions with accounting of different plasmachemical reactions between them. Simulations predicted the main regions of the dc glow discharges including cathode and anode sheath and plasma of negative glow, Faraday dark space and transition region. Gas heating plays an important role in shaping the discharge profiles.

Experimental setup. The discharge installation enabling promptly to use electrodes of various forms and smoothly adjust the interelectrode gap with a precision of about 1 μm with a help of a simple lever system was developed and manufactured. Voltage U_{test} at a regulated limiting resistor R and the voltage at the discharge U_{dis} are given to a two-channel oscilloscope OWON PDS5022S through the same voltage dividers 1:1000 with an input resistance of 10 MOm Video of discharges at a rate of 50 fields per second and a resolution of 720x576 p. are received with the help of camcorder SONY HDR-HC9.

Fig.1. Microdischarge at different gap

Current Voltage Characteristics of short microdischarges.

Fig. 2 shows that in all the range of currents (5 - 50 mA) minimum of discharge voltage with a steel cathode corresponds to the gap length of approximately 30μ unlike the Paschen's law curve. This difference indicates a respective decrease in the density and the increase of

the gas temperature at the zone of the discharge which occurs because of the high normal current density of the glow discharge at atmospheric pressure, and the possibility of their measurement by this method.

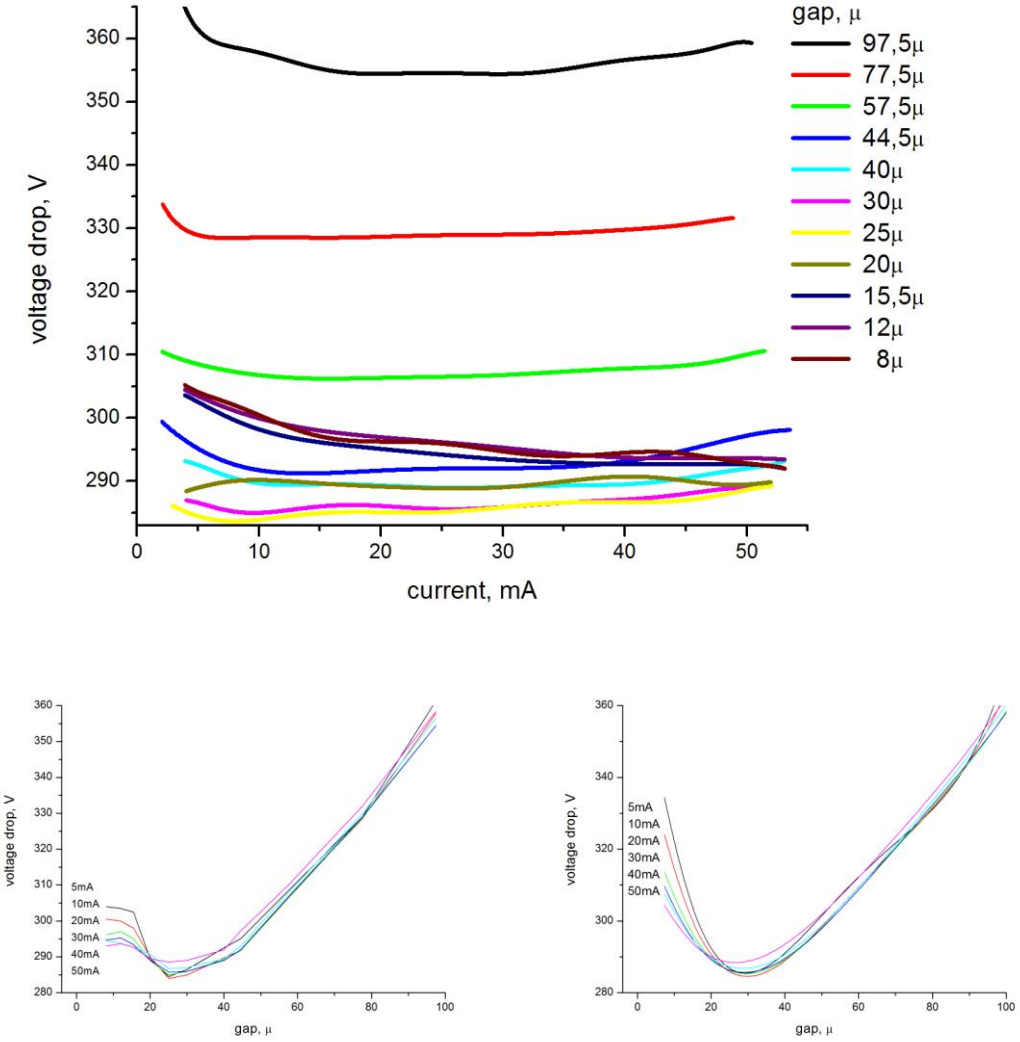

Fig.2. CVC and the dependence of the discharge voltage on the gap

Conclusion. The research of the short glow discharge at the atmospheric pressure in conditions of homogeneous, weakly and strongly inhomogeneous fields had been carried out. The measurements were carried out in the pulse mode with synchronous video recording which allows to account or significantly reduce the influence of thermal and dynamic non-stationarity as well as the short-term instability of the discharge. The associated rise in the accuracy of the measurement allowed to confidently obtain the dependence of the voltage burning glow discharge with flat electrodes of stainless steel on the size of the gap near its minimum (30 μm) under the atmosphere conditions. The ability of a glow discharge to relatively stable burning at the atmosphere at the left branch of this dependency had been proved (at 20 μm). However, certain interpretations of these results are possible only after their measurements at different pressures in combination with measurements of current density.

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Effects of the Secondary Electron Emission Coefficient in Radio Frequency Oxygen Discharge

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We use a global model (volume averaged) and a Langmuir probe to investigate the plasma parameters of an oxygen asymmetric capacitive radio frequency discharge in a pressure range of 10-80 mTorr and 30-200 W of input power range. The discharge contains several species such as O_2^+, O^-, electrons, ground state O_2 and O atoms, and metastables $O_2(a1\Delta g)$ and O(1D). The dominant process of generation of O^- is the dissociative attachment, while the loss processes are electron impact detachment, mutual neutralization and detachment. It is obtained a good agreement between simulations and measurements for the electron temperature, mainly for pressures above 25 mTorr. However, for pressures below 25 mTorr the discrepancy is higher, because in these cases the EEDF is not Maxwellian, as it is considered in the global model for all pressure ranges. The influence of the secondary electron emission (γ_{se}) from the electrodes, on the plasma properties, is also verified. As the secondary electron emission from the electrodes increases, the electron density also increases as a result of high ionization rates. In this case there is a better agreement between the results from global model and Langmuir probe measurements.

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A General View of Plasma Space Propulsion Physics and Technology

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Plasma thrusters are challenging the monopoly of chemical thrusters in space propulsion. The electromagnetic energy (per unit of mass) that can be deposited into a plasma beam can be orders of magnitude larger than the specific chemical energy of known fuels. This implies large savings in propellant and launching costs. The first figure of merit of a space rocket is the specific impulse c, which coincides approximately with the exhaust velocity of the jet of gas. Common chemical rockets have c ~2.3 km/s, whereas plasma thrusters can cover the range c ~6−100 km/s.

Plasma thrusters constitute today a large and varied family, with nominal powers ranging from subwatt to megawatt. Some devices are already commercialized (the gridded ion thruster, the Hall effect thruster, the arcjet, and the pulsed plasma thruster), other ones are incipient laboratory prototypes. Plasma thrusters are also classified according to the processes for plasma production and acceleration. Plasma production and heating is achieved by either DC electrodes or AC antennas. DC biased electrodes are used in matured designs and electrode erosion often limits the thruster lifetime. Many designs under current research opt for powering the plasma with RF or microwave antennas. The momentum equation for a fully-ionized, stationary plasma, reads

$$\nabla\cdot(\rho\vec{u}\vec{u}) = \varepsilon_0(\nabla\cdot\vec{E})\vec{E} + \vec{j}\times\vec{B} - \nabla\cdot\bar{\bar{P}}$$

where symbols are conventional. $\vec{E}$ and $\vec{B}$ can be either applied externally or self-induced by the plasma. Both ρ and $\vec{u}$ are determined by the massive ions, the electric current $\vec{j}$ is due mainly to electrons, and the pressure tensor involves both plasma species. Except for minor contributions, thrust is the integral of the axial momentum flux of the plasma over a perpendicular plane to the beam. Depending on the dominant term in the right-hand-side of the above plasma momentum equation, plasma acceleration is electrostatic, electromagnetic, or electrothermal. The classical electrothermal thruster is the arcjet but this is basically a chemical thruster with gas superheated by a plasma arc formed at the center of the jet.

Genuine plasma thrusters ionize near most of the gas injected in their chambers. Typical ranges of densities and temperatures are $n_e \sim 10^{17}$−10^{20}m^3 and $T_e \sim 1$−50eV, and the plasma is quasineutral except in thin layers around walls and electrodes. Frequently the plasma is weakly-collisional too, which allows magnetic confinement but keeps the plasma off local thermodynamic equilibrium, with the resulting uncertainties on the species velocity distribution function and the plasma transport coefficients. Next, several thrusters are selected in order to illustrate most relevant plasma propulsion physics.

The *gridded ion thruster* is an electrostatic accelerator consisting of a discharge chamber and a set of two or more grids. These extract the positive ions from the chamber and accelerate them to energies of ~1-3 kV. Simultaneously, the grids act as a double-side

electron barrier. An external hollow cathode provides the electron current that neutralizes density and current of the expelled ion beam. The grid system is a critical element. First, the ion current density extracted from the chamber is upper-bounded by space-charge saturation at the grids (known as the Child's law). Second, grid transparency, separation, and alignment must satisfy conflicting requirements. This makes ion thrusters high-voltage, low-current, and bulky devices.

Gridded ion thrusters may differ on the ionization mechanism. In the classical DC ion thruster a second hollow cathode, placed in the chamber, injects primary electrons of 10-20eV that drive ionization. Efficient ionization requires magnetic confinement of the plasma, which is achieved usually with a cusped-field configuration. AC ion thrusters replace the internal hollow cathode by a RF or microwave antenna that is coupled to the plasma either inductively or by electron cyclotron resonance. The RF ion thruster does not require magnetic confinement. Making it simpler to operate. DC ion thrusters have already a long record flight, while AC ion thrusters have flown successfully too.

The *Hall-effect thruster* (HET) is an electromagnetic accelerator with long flight heritage too. The conventional design consists of an annular, dielectric chamber with the gas injection and the metallic anode at its back. An external hollow cathode acts as cathode and sole source of electrons. A fraction of these electrons travel inwards to ionize the gas, and the rest neutralizes the expelled ion beam. Except in sheaths around walls the plasma is quasineutral and the self-adjusted ambipolar electric field governs ion and electron dynamics. In order to have suitable plasma density and efficient gas ionization, the axial electron flow is strongly inhibited by a near-radial magnetic field of a few hundred Gauss, externally applied. This magnetic field induces the azimuthal drift of electrons, increases their residence time in the chamber about 100 times, and makes their axial flow to rely on collisional and turbulent transport. The magnetic field is too weak to affect directly the ion motion, but it shapes the electric potential 2D profile.

Fluid and particle-based models have been successful in explaining the complex interplay of phenomena and parameters in a HET discharge, but there are two central phenomena that are still incompletely mastered: plasma-wall interaction and transverse electron diffusion. Main *plasma-wall interaction* processes are energy losses and ion sputtering. Since lateral walls are not screened magnetically there is significant recombination and energy deposition. In addition ceramic materials present a large electron secondary electron emission by electron impact that reduces greatly the confinement of primary electrons. Nonetheless, the weak plasma collisionality makes uncertain both the replenishment of the tail of energetic electrons collected by the walls and the evolution of the beams of emitted secondary electrons. A HET lifetime is limited by large wall erosion caused by *ion sputtering*. Reliable simulations of sputtering would be very beneficial for lifetime testing but they require good knowledge of the ion velocity distribution function and the sputtering yield of the wall ceramic compound.

Perpendicular electron transport in a HET is not classical (even if wall collisionality is included) and seems to be dominated by *turbulent diffusion*. This would be due to correlated azimuthal fluctuations of plasma magnitudes that would leave a stationary azimuthal force on electrons, but authors differ on whether the main effect comes from low or high frequency modes. There is a large amount of *plasma oscillations* in a HET, propagating either azimuthally or longitudinally, ranging from a few kHz to tens of Mhz. Some relevant longitudinal, low-frequency fluctuations, such as the ion-transit and the breathing modes are reasonably understood, but this is not the case of the azimuthal modes.

The *thruster with anode layer*, the *cylindrical HET*, the *mini-HET with permanent magnets*, the *two-stage HET*, and the *HET with magnetic cusps* are variants of the conventional HET design that try to offer different performance improvements.

The *magneto-plasma-dynamic thruster* (MPDT) consists of an annular chamber with a central cathode and an annular anode. Near-radial plasma current is established between them which induces an azimuthal magnetic field. This creates the axial magnetic force that drives the current-free plasma jet. Ionization is achieved by electrons heated collisionally. The MPDT becomes a near-competitive electromagnetic accelerator only at high currents and power (~10^4A and ~1Mw, respectively). Even then, there are important energy losses and erosion at the electrodes. Furthermore, the *onset phenomenon* sets an upper bound to the discharge current and power of a MPDT. That phenomenon would basically be plasma arc instability, triggered when full ionization is accomplished and plasma tends to filamentation and over-heating, leading to strong fluctuations and enormous electrode erosion. The *applied-field MPDT* adds an applied magnetic field to improve thrust in the 100 kW range, but the 3D physics of these devices are not well comprehended yet.

The *helicon thruster* is a helicon source modified in order to operate at high plasma temperatures and to accelerate efficiently the plasma beam. It is a good example of advanced plasma propulsion, which uses RF waves to produce hot plasma and a magnetic nozzle to accelerate it. The chamber consists of a glass tube surrounded by a RF antenna emitting on the 1-26 Mhz range and a set of coils that generate a near-axial magnetic field of the order of 500-2000 G. Within a certain range of plasma densities and applied magnetic field, helicon waves propagate within the whole plasma column, and transmit their energy to the plasma via several mechanisms, such as mode conversion to dissipative Trievelpiece-Gould waves. This *helicon mode* creates much denser plasmas than the *inductively coupled mode* recreated in other devices, such as the AC ion thruster.

Inside the helicon source, the magnetically confined plasma develops an azimuthal current, as in a *theta-pinch* arrangement, and collimates the plasma beam. Outside the chamber, the divergent magnetic lines guide strongly-magnetized electrons. Weakly-magnetized ions are drifted radially by an ambipolar electric field, thus completing the nozzle effect on the plasma. The *magnetic nozzle* has no walls, thus reducing energy losses and thruster heating. The thrust gain in a magnetic nozzle comes from the magnetic force exerted by the plasma azimuthal current on the thruster coils. After completing the supersonic expansion, the plasma needs to detach from the magnetic lines before they turn back and close on themselves. Plasma detachment mechanisms, ranging from resistivity, to electron inertia, and induced magnetic field are much discussed at present. The magnetic nozzle is the acceleration stage of other advanced plasma thrusters like the applied-field MPDT and the VASIMR, but expansion processes are different in each of them.

Suprathermal electrons can form in helicon sources, although formation conditions and their role in plasma ionization and expansion are unclear. These electrons promote the development of a *current-free double layer* (CFDL) in the supersonic plasma, due to anomalous thermodynamics of the resulting plasma. The *helicon double layer thruster* concept gives a central propulsive role to the CFDL because it is an ion accelerator, but this idea is much disputed since a CFDL does not increase plasma momentum.

Challenges on the Development and Performance of a Permanent Magnet Hall Thrusters - PHALL

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The Plasma Physics Laboratory of UnB (Fig. 1a and 1b) has been developing a Permanent Magnet Hall Thruster since 2002. The project consists on the construction and characterization of plasma propulsion engines based on the Hall effect.

Fig.1(a). Plasma Physics laboratory facility for PHALL diagnostics and tests

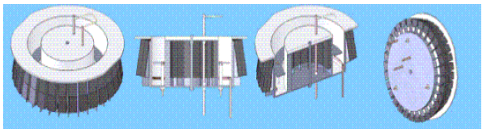

Fig.1(b). PHALL I with permanent magnets arrangements views

This thrusting system is designed to be used in satellite attitude control and long term space missions. One of the greatest advantage of this kind of thruster is the production of a steady state magnetic field by permanent magnets providing electron trapping and Hall current generation within a significant decrease on the electric energy supply and thus turning this thruster into a specially good option when it comes to space usage for longer and deep space missions, where solar panels and electric energy storage on batteries is a limiting factor. Two prototype models of permanent magnets Hall Thrusters PHALL I and II were already developed and tested with different permanent magnets systems. In this work we will describe the plasma diagnostics system used on the plasma characterization, thrust and specific impulse measurements. Langmuir probes are used for plasma density and temperature measurements. Faraday Cup Ion probes and Spectrograph (Andor SR-750-B2, within 435 nm to 700 nm) line broadening measurements are used to measured ion temperature and transport from Hall current channel to the plasma ejected plume. In order to control argon plasma fuel purity a quadrupole mass spectrometer, a Leybold Transpector 1-300 UMA, is used.

Important to notice plasma physics phenomena, that may significantly interfere in PHALL performance is the occurrence of instabilities that can occur inside and outside of the Hall current channel. In order to better understand the turbulence and plasma oscillations that occur during the thruster´s operation, we propose and test a wide frequency range instability detection system based on a RF (radio frequency) detection probe connected to a Spectrum Analyser (Agilent CSA 100 khz-6 Ghz) is used. Instabilities on the PHALL discharge current is also monitoring using a real time data acquisition system, based on a PCI-DAS

1602/12 board containing 16 analogic inputs, 24 digital channels operating within a 330 khz sampling rate.

In the near future we expect to develop life tests systems for these thrusters in vacuum systems with bigger volume and pumping speed capability. A direct thrust and specific impulse measurement instrumentation it is been also considering.

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PION5 Performance Study in the Production of Thrust
Conference on Plasma Assisted Technologies (ICPAT)

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The development of Kaufman-type ion thrusters began in Brazil in 1985 by the Associated Plasma Laboratory (LAP) at National Institute for Space Research – INPE. The ion thrusters should have low power consumption and a small size to meet the requirements of the satellites of Brazilian Complete Space Mission. Since then, a series of three prototypes were tested and served to demonstrate that such technology was viable in the country [1]. The present thruster model (PION5) has a beam extraction section of 5cm and it was designed based on the experience of the previous thrusters, and aimed at testing new technologies such as: hollow cathodes, magnetic coils for main plasma magnetic containment and grids system for ion beam acceleration. Numerical codes were used in the design of this new engine, such as KARAT [2] for the study of plasma generation and magnetic containment quality and IGX [3] to study the ion optics of the grids system.

PION5 consists of five main sections: cathode enclosure, anode, grids system magnetic assembly, and neutralizer, as shown in Fig. 1. The cathode enclosure comprises a chamber where there is inside a gas manifold for the main discharge propellant feeding, a hollow cathode with enclosed keeper and a baffle. The magnetic assembly consists of a Helmholtz pair and a ring permanent magnet radially magnetized. A pair of molybdenum grids electrically insulated by ceramic insulator comprises the grids system. All these components are surrounded by a metallic piece intended for both electrical and magnetic shielding. The magnetic shielding is done by both front and the back covers made using Mu-Metal. Finally, a hollow cathode with enclosed keeper comprises the neutralizer located outside of the shielding of the thruster.

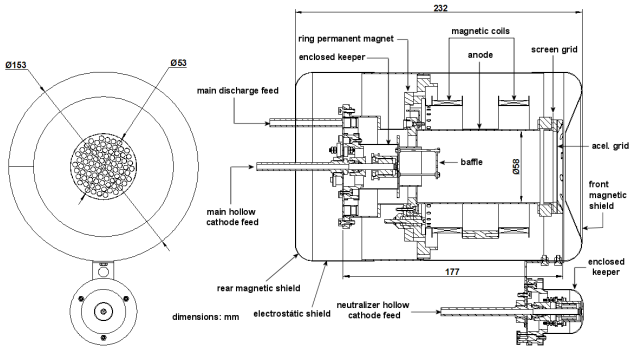

Fig.1. PION5 Kaufman-type ion thruster schematics

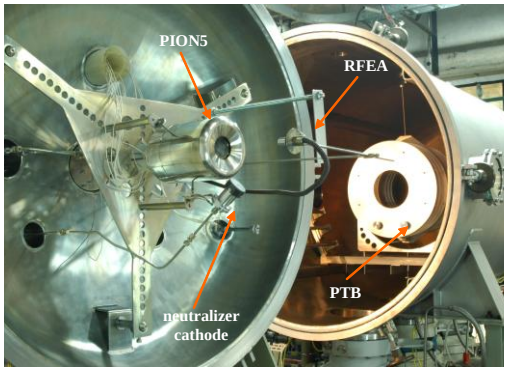

Fig.2. PION 5 experimental apparatus

Grade 304 stainless steel was used in the most parts of the thruster. Alumina and boron nitrate were the

machinable ceramics used to make the electric insulators. Both the screen and accel grids were made with molybdenum, and containing each one 1285 holes opened by LASER machining.

The performance ground based tests with PION5 were carried out in a 1.2 m diameter by 3 m length vacuum chamber pumped by three cryo-cooled diffusion pumps which all performs 6000 l/s of pumping speed for nitrogen. The base pressure of the vessel is $7 \cdot 10^{-7}$ mbar and the ultimate pressure is in the range of $1 \cdot 10^{-5}$ to $6 \cdot 10^{-5}$ depending upon the gas load. Argon was the propellant in all performance tests since it was the gas available at this time. A retarding field energy analyzer (RFEA) and a pendulum target thrust balance (PTB) [4] are the main diagnostics for ion beam characterization. PION5 installed on the movable door of the vacuum chamber is shown in Fig. 2.

The hollow cathodes consist of a 5-mm diameter by 40-mm long, 0.3-mm-wall thickness tantalum tube, with a cold-pressed 1-mm diameter orifice tungsten tip. The insert consists of a 5-turns rolled tantalum foil painted with a thin layer of mixed carbonates, (Ca, Ba, Sr)CO_3, which are all converted to oxides by heating the insert up to 900 ^oC. The cathode heater comprises a body of boron nitride machined in the shape of a revolver cylinder, in which holes a coiled tungsten filament is passed through. This heater expends 90 W to heat the cathode at the temperature of conversion the carbonates to oxides. All cathodes are equipped with metallic enclosed keeper which tip is made of graphite.

Diverse experimental studies were carried out to investigate the dependence of the discharge parameters on the magnetic field strength and propellant mass flow rate [5]. These results will be shown timely.

Table 1. PION5 operating parameters

Operating parameter	Value
I_D, A	9
V_D, V	42.5
Main cathode mass flow rate, mAeq	0.32
Main discharge mass flow rate, mAeq	0.32
Total coil current, A	6.5
RFEA distance from accel grid, mm	230
PTB distance from accel grid, mm	1400
Neutralizer keeper current, A	1.5
Neutralizer keeper voltage, V	27
Neutralizer mass flow rate, mAeq	0.11

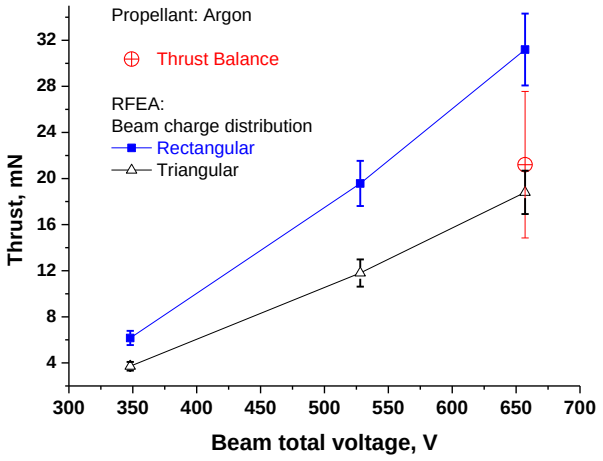

Fig.3. Thrust level as function of beam total voltage. Results from RFEA and PTB.

Table 2. PION5 operating parameters

Thrust	Specific Impulse	Thrust-to-power ratio
20 mN	5851 s	19.8 μN/W

Setting the discharge parameters to those ones in Table 1, the thruster was tested in terms of thrust production as function of the total beam voltage. The results from RFEA reveal a beam divergence angle of $30^o \pm 10\%$ which produces thrusts levels in the range of 6 mN to 31 mN if a rectangular (uniform) beam density distribution was adopted (blue plot in Fig. 3), and in the range of 3 mN to 19 mN if a beam density triangular distribution, for beam total voltages varying from

350 V to 657 V, as shown by the black plot in Fig. 3. The maximum beam total voltage was that one with which the ion beam propagates free of sparks in the chamber. It is believed that sparking starts because the high ultimate pressure of $5 \cdot 10^{-5}$ mbar during the thruster running. Lower ultimate pressures demand improving the vessel pumping speed at least one order of magnitude.

The PTB result is only for the upper most level of thrust because the tests aimed to find out the extreme operating condition of the thruster. This is represented by a single red point in Fig. 3 and is equivalent to 21 mN ±30%. The main PION5 performance parameters are, then, compiled in Table 2, representing the thruster operation under the extreme condition.

Conclusion

The PION5 ion thruster has demonstrated an excellent capability on both plasma generation and in producing thrust, thanks to the detailed numerical modeling validated by the overall good performance of the thruster. Both hollow cathodes (main and neutralizer) have revealed to be both reliable and efficient for ion thruster ground based tests, and, in turn, the flexible magnetic field have proved to be a powerful resource for the plasma generation with both suitable charge density and volume simply by varying the electric current of the coils.

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Analysis of a Two-Stage Pulsed Plasma Thruster Performance Parameters

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Nomenclature

Δm	=	Total mass lost during a single discharge cycle
ε_1	=	Discharge energy of the primary discharge
T_P	=	Steady state propellant temperature immediately before the discharge
α_1, β and σ	=	Ablation constants obtained experimentally
τ_E	=	Mass that is accelerated electromagnetically during the discharge
τ_G	=	Mass of the gas-dynamically accelerated propellant
I_{bit_1}	=	Impulse bit solely due to the first discharge
F_P	=	Total force due to the first discharge
t_1	=	Time in which the primary capacitor is fully discharged
t_2	=	Total time during which the propellant is sublimating
F_{P_1}	=	Force due to the electromagnetically accelerated particles (1st stage)
F_{P_2}	=	Force due to the gas dynamically accelerated mass (1st stage)
ε_2	=	Energy of the secondary discharge
F_S	=	Total force due to the secondary discharge
t_3	=	Time when the secondary discharge starts
t_4	=	Time when the secondary discharge ends
t_5	=	Time when no more gas dynamic forces are produced
F_{S_1}	=	Force due to the electromagnetically accelerated particles (2nd stage)
F_{S_2}	=	Force due to the gas dynamically accelerated mass (2nd stage)

A two-stage pulsed plasma thruster (TS-PPT) [1] is a particular type of a High Frequency Burst PPT (HFB-PPT) [2] space propulsion device that was investigated elsewhere [3]. The TS-PPT is a type of solid propellant ablation-fed pulsed plasma thruster (PPT) that uses PTFE as a propellant. The TS-PPT aims at increasing the regular pulsed plasma thruster (PPT) propellant utilisation. Typically regular PPTs are able to accelerate electromagnetically only 40-60% of the propellant [4]. The

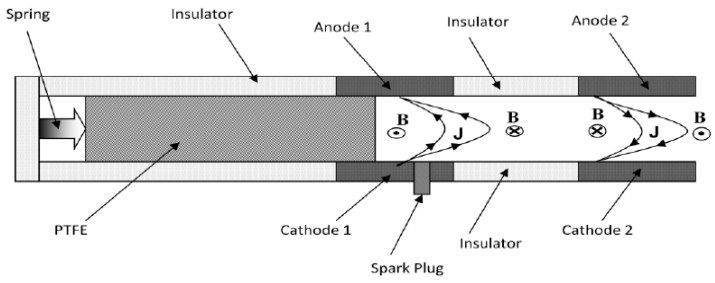

Fig.1. Schematics of a Two-Stage PPT

cause of the poor utilisation of the propellant is the late time ablation (LTA) that is the sublimation of propellant that takes place after the electric discharge on the surface of the PTFE is finished [5]. The LTA is a low speed gas (~500 m/s) that contributes very little to the total impulse of the PPT. The TS-PPT employs an additional electric discharge with the aim of accelerating the LTA and thus increasing the propellant utilisation. This work presents an analysis of the experimental results obtained with the TS-PPT [6].

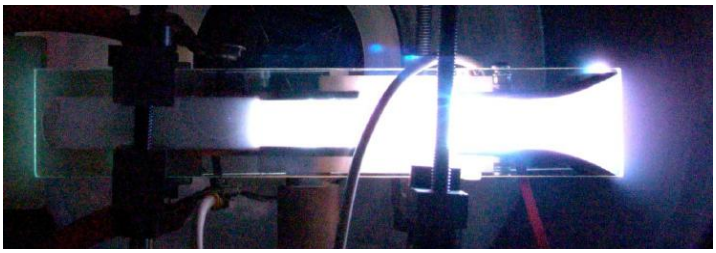

Fig.2. Laboratory Two-Stage PPT during operation.

The Two-Stage PPT

The TS-PPT comprises two pairs of electrodes, as show in Fig. 1. The first pair of electrodes is mainly responsible for propellant dosing and the second pair of electrodes is mainly responsible for propellant acceleration. When considering the first pair of electrodes alone the TS-PPT resembles a regular PPT with the difference that the aim of the first pair of electrodes is to ablate the amount of propellant that will take place in one whole cycle of discharge of the TS-PPT. Notwithstanding, the first pair of electrodes (also known as first stage) of the TS-PPT also accelerate electromagnetically the propellant being ablated while the electric discharge is taking place. The second pair of electrodes (or second stage) is placed downstream, far enough from the propellant surface to avoid ablating more propellant and also to avoid producing more late time ablation (LTA). One prototype of a TS-PPT was built with the purpose of validating the hypothesis that it is possible to have the second pair of electrodes (second stage) discharging on the LTA. The prototype built had its second stage discharging on both the incoming plasma from the first stage and later, after the first stage's discharge was over, the second stage kept its electrical discharge on the LTA. Fig. 2 shows the TS-PPT operating in vacuum. Experimental data indicates that specific impulses as high as 4000s are possible when employing a TS-PPS, indicating that the TS-PPT indeed utilises the propellant more efficiently than a regular PPT.

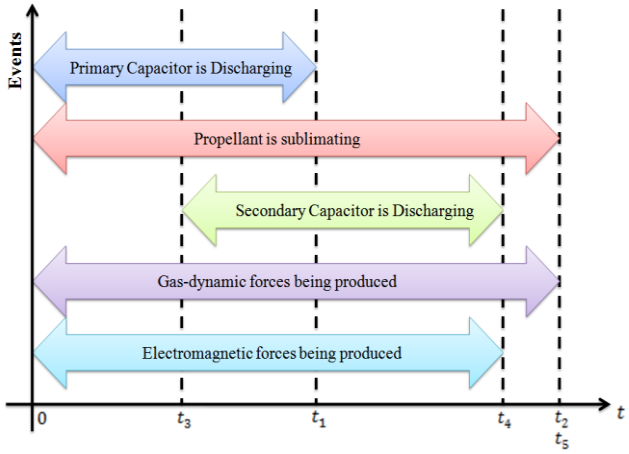

Fig.3. Time diagram of a discharge cycle of the two-stage PPT

Simple Analytic Model of The Late Ablation Mechanism

The complexity of the thrust production in a TS-PPT can be observed from the diagram on Fig. 3. It can be seen that while both the first stage and second stage capacitors are discharging, there are electromagnetic forces being produced. The gas-dynamic forces can be produced past the end of both stage capacitors discharge and last while there is propellant sublimating.

The novelty of the TS-PPT, compared to the regular (single stage) PPT, is that by adding the second stage the TS-PPT can impart an extra energy to the propellant without increasing

the total mass that participates in the ablation, as Δm is independent of the second stage discharge:

$$\Delta m(\varepsilon_1, T_P) = \alpha_1 \varepsilon_1 + \beta {T_P}^{\sigma} = \tau_E + \tau_G \quad (1)$$

The total impulse bit due to the first stage is:

$$I_{bit_1}(\varepsilon_1, T_P) = \int_0^{t_2} F_P \, dt = \int_0^{t_1} F_{P_1} \, dt + \int_0^{t_2} F_{P_2} \, dt \quad (2)$$

and the total impulse bit due to the second stage is:

$$I_{bit_2}(\varepsilon_2, \Delta m) = \int_{t_3}^{t_5} F_S \, dt = \int_{t_3}^{t_4} F_{S_1} \, dt + \int_{t_3}^{t_5} F_{S_2} \, dt = \int_{t_3}^{t_5} \left(F_{S_1} + F_{S_2} \right) dt \quad (3)$$

The second stage does not produce late ablation. However, there may be both gas-dynamic and electromagnetic forces during the second stage operation, as the propellant may be still be sublimating and not necessarily all propellant may be able to be electromagnetically accelerated.

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He is the inventor of the High Frequency Burst Pulsed Palsma Thruster and the Two-Stage Pulsed Plasma Thruster (or Double Discharge Pulsed Plasma Thruster) and had his patent granted in 2008. He did his Post-Doctoral Research at the University of Southampton (UK) in the Hiper Project - High Power Electric Propulsion A Roadmap for the Future - in the Dual Stage Four Grid Ion Thruster (DS4G) of the European Comission. He is now a Researcher at the Combustion and Propulsion Laboratory of INPE in Cachoeira Paulista – São Paulo State, Brazil, working as a Brazilian government federal employee.

Possibles Equilibria in Microhollow Cathode Discharges

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Recently, due to the reduction of the dimensions of the devices used in the generation of plasmas, the term microplasmas emerged in the scientific word. This term is only valid for plasmas whose dimensions are less than 1 mm. At the beginning of this century, there was a significant increase in jobs involving microplasmas. A major advantage in the generation of microplasmas in relation to conventional plasmas is related to the low cost experimental apparatus. Regarding their applications are bacteriological decontamination [1], [2], thin film deposition [3], etc.

Fig.1. Discharge chamber and electrical measurements equipments

The configurations of microplasmas generators found in the literature, as well as the materials used in its fabrication are as different as possible. In the case of this work, the configuration chosen for the study of microplasmas was open microhollow cathode (OMHC), which is formed by a capacitor of plane-parallel plates with a dielectric (mica) between them and a hole diameter (diameter chosen: 250 μm, 500 μm and 1000 μm), perforating the center of the plates along with the dielectric. This device was powered by a high voltage source of direct current (DC). As electrodes, we used copper, molybdenum and tantalum to produce OMHC discharges. In relation to the experimental conditions, our microplasmas were generated in a gas mixture, Ar-H_2, for pressure range 90-800 Torr. To perform the spectroscopic analysis we used a high resolution optical spectrometer with a focal length of 1 m. Fig. 1 shows the reactor used to generate our microdischarges.

Some of the goals of this study was to conduct a more thorough analysis of possible equilibria (Saha, Boltzmann, Maxwell and Planck Equilibrium) presented by microplasmas through the profiles of the atomic states distribution functions (ASDF) of the neutral atom of argon (Ar I). The atomic states distribution functions (ASDF) which describes how the neutral atoms and ions are distributed in relation to their quantum states has a lot of information from the plasma where these neutral atoms and ions are inserted. Since it results from the combination of microscopic processes, these activities are reflected in ASDF which in turn provides a good description of the plasma. From the results, it was found that the microdischarges generated in OMHC did not show complete thermodynamic equilibrium

(TE) and local thermodynamic equilibrium (LTE), but presented, according to the experimental conditions, both the partial and local Saha equilibrium (pLSE [4]).

According to Figs. 2 (a)-(d), it was found that the microplasmas tend to achieve the thermodynamic equilibrium depending on the local augmentation of the pressure in the reactor. It was also found, as shown in Fig. 2 that the electron density increases with pressure due to ionization efficiency of the medium. Regarding partial balances, which has the partial local Boltzmann equilibrium is present in all Fig. 2 (a)-(d) belonging to the states at 4p and part of states belonging to the 5p level. While both Saha and Maxwell partial and local equilibrium is present only on the Fig.2 (d) due to the overlapping tail of experimental ASDF with Saha distribution. Under all experimental conditions, our microplasmas are ionization-type [4], hence this implies that there are transport of particles away from the active region of the plasma, causing this loss of thermodynamic equilibrium.

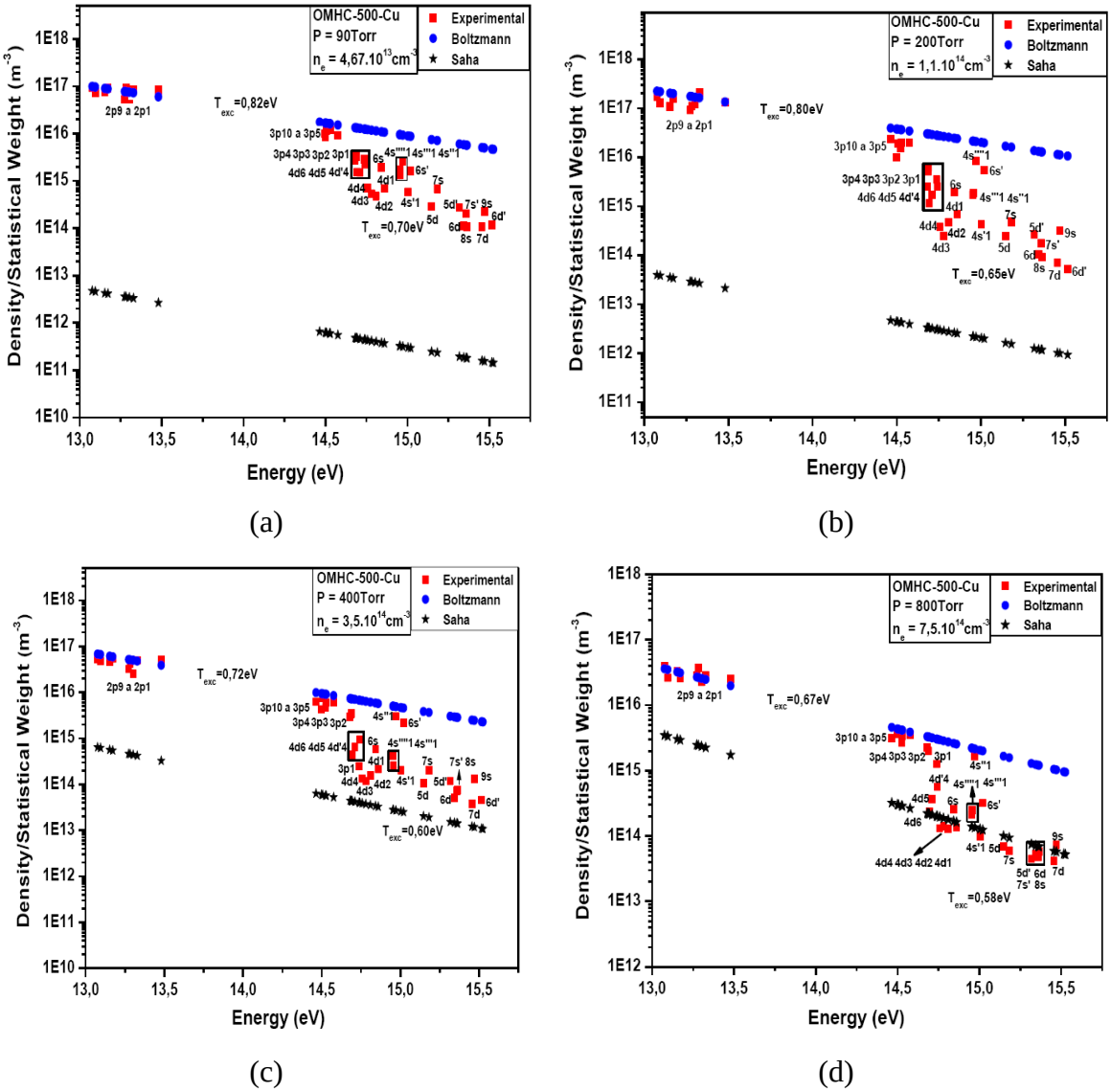

Fig.2. (a)-(d) ASDF of Ar I cupper MHC with hole diameter 500µm and pressures of 90, 200, 400 and 800 Torr

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HF Plasma Discharge for Surface Modification of Cellulose-Based Materials

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As a "dry" technology, plasma is ecological and environment friendly and can be used to modify the properties of the surfaces of a wide range of materials, including polymers.

The practical applications of plasma are nowadays extending to the field of cultural heritage conservation, where the need of less noxious treatments is claimed by sensitive objects containing cellulose or collagenous polymers. This area of research requires the development of reliable and versatile systems for the activation or modification of polymer surfaces, providing the possibility to act only on the top layers without acting on the bulk of the material. Such eco-efficient processes can be provided by the cold plasma systems; recent studies highlighted the possibility of using high frequency generated plasma for the decontamination of objects made from organic materials [1] or for cleaning the surface of the paintings [2].

Further researches were now carried out on cellulose – based materials, using an experimental set-up especially designed for treating cultural heritage objects; the plasma state is generated by the use of a high frequency (HF) discharge, while the system configuration enable to perform decontamination, cleaning and protective coating treatments [3] (Fig. 1).

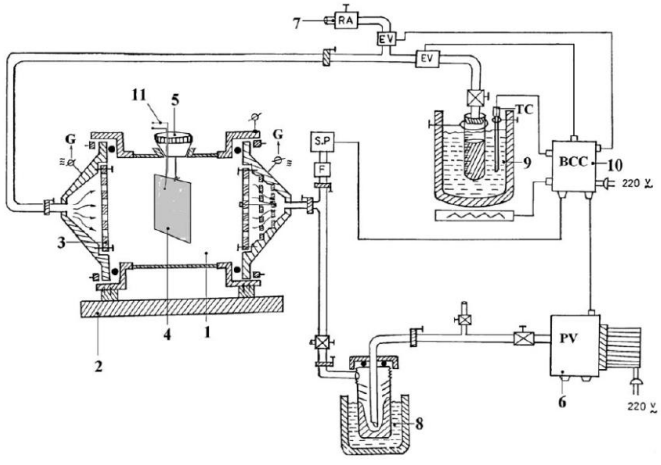

Fig.1. Experimental set-up used for HF cold plasma treatment [3]

The study is presenting the modifications induced at atomic and molecular level on the surface morphology of model samples of cotton paper under the following experimental conditions: the maximum temperature of 40 °C, the electric field intensity between 20 and 30 V/cm, the discharge power of 100 W, at a pressure of $1.5 \cdot 10^{-1}$ mbar in the reactor. The

treatment was using an O_2 / Ar gas mixture of 1:4 and the time was varried at 30 min and 60 min.

The surface analysis was carried out using contact angle measurement, X-ray photoelectron spectroscopy (XPS) and ATR-FTIR spectroscopy. Two competitive processes took place when cellulose polymer was exposed to plasma: functionalization and etching. The working conditions determine which processes is dominant. XPS measurements confirmed the incorporation of oxygen containing groups on the surface after treatments, while modifications in the surface chemistry (evidenced by ATR – FTIR) and in the morphology changed the surface hydrophilicity. The improved wettability of the polymer observed after the plasma treatment is favourable for a subsequent deposition of specific protective coating formulas in the conservation practices. The etching process that occurs at atomic level of the material can lead to the cleaning of contained impurities or degraded areas. At the same time, for the used working atmosphere the HF plasma treatment is well suited for decontamination purposes onto the polymer surface.

The preliminary findings indicate the possibility of using HF plasma discharge for obtaining modified properties of the cellulose-based surfaces, by refining the working parameters, in order to overcome the limitations of the conventional chemical processes applied in the paper conservation field worldwide.

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Recalcitrance of Sugarcane Bagasse before and after Water Plasma Pretreatment

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The use of various types of plant biomass as renewable energy sources, even not being able to completely replace the use of oil and its derivatives, should be considered a significant reduction in negative environmental impacts that are caused by its consumption. Several nations in the world have been organizing strategically to obtain this new means of generating energy [1].

The use of cellulosic materials are a big source of energy and has a good potential for the production of ethanol, bagasse from sugar cane is one of the most used in Brazil. This is due to the fact that the bagasse brings several advantages, as it is in a form processed by milling mills, in large quantities and can be used on site, thereby reducing transport costs, making the production more accessible and low cost [2].

The use of bagasse for energy purposes may be performed through combustion and gasification processes where their polysaccharides can be released by hydrolysis and then be converted by fermentation to ethanol. To get a more effective conversion of biomass found as straw or bagasse, it is necessary to subject the feedstock to a pretreatment process [3]. Several pretreatment methods have been proposed for separation and utilization of lignocellulosic materials, these methods are divided into mechanical, physical, chemical, biological or combination of these [4].

However, considerable technical improvements are still needed before efficient and economically feasible lignocellulosic biomass-based bioethanol processes can be commercialized. One of the major limitations of this process is the consistently high cost of enzymes involved in the conversion of the cellulose component into fermentable sugars [5]. Achieving rapid and complete enzymatic hydrolysis of lignocellulosic biomass at low protein loadings continues to be a major technical challenge in the commercialization of cellulose-based processes converting biomass to ethanol [6], [7].

The efficiency of cellulose enzymatic saccharification is correlated with pretreatments and microfibril accessibility for cellulolitic enzymes. The performance of hydrolyze of sugar cane biomass with regular enzymatic cocktail achieve a steady state after some hours. The steady state occur because during the hydrolyze time course the concentration of sugars like glucose and cellobiose is keeping constant and the residual hydrolyzes lignocellulose materials are more them 50% from initial mass [8]. Many articles reported the hydrolyses recalcitrance of lignocellulose and due to the recalcitrance many others have been reporting different kinds of pretreatments [9]-[11]. However there is a gap between recalcitrance

studies related with pretreatments of sugar cane from micro to nano scale and a deeper understanding of pretreatments of cellulose structure is required to overcome the natural recalcitrance of lignocellulosic materials [12].

An effective and economical pretreatment should meet the following requirements: (a) production of reactive cellulosic fiber for enzymatic attack, (b) avoiding destruction of hemicelluloses and cellulose, (c) avoiding formation of possible inhibitors for hydrolytic enzymes and fermenting microorganisms, (d) minimizing the energy demand, (e) reducing the cost of size reduction for feedstocks, (f) reducing the cost of material for construction of pretreatment reactors, (g) producing less residues, (h) consumption of little or no chemical and using a cheap chemical [13].

Considering this lack of pretreatments more efficient, this study used a plasma reactor with dielectric barrier discharge, where the micro discharges that occur during the process has directly affect the liquid present in the reactor, doing treatment in all biomass which is submerged in water, Fig.1.

This type of discharge produces a large volume of non-thermal plasma at atmospheric pressure, such plasmas are sources of highly reactive species (radicals, ozone, excited atoms and molecules) [14]. Once all biomass is submerged in water during process ensures the interaction of these reactive species with the interior of biomass and not only its surface, this causes occur removal of lignin, hemicellulose by decreasing the crystallinity of cellulose and increasing its porosity allowing the remaining solid biomass is more accessible to the enzymes.

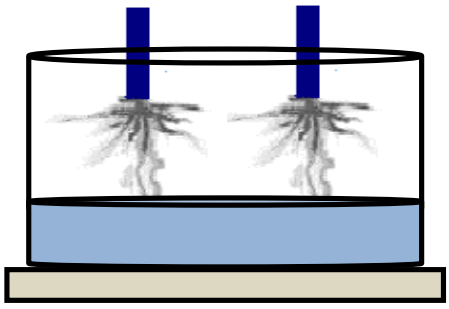

Fig.1.

The samples were treated in a glass reactor having a grounded metal plate were used four electrodes made of stainless steel and a source of alternating current of 30 mA and voltage of 14 kV, disruption of the plasma occurs between 2 ~ 3 kV depending on the distance between the electrodes and the surface of the liquid.

For the tests were used sugar cane bagasse "in natura", 7 grams of a sample was subjected to the plasma treatment for 1 hour. The water used in the process was analyzed with respect to its pH, temperature and chemical composition after treatment of biomass. The plasma treated sample was compared with untreated samples; all samples were scanning electron microscopy (SEM) and Atomic Force Microscope (AFM). The results demonstrate that the samples treated with plasma reactor liquid showed an amorphization compared to untreated samples, Fig. 2 shows images obtained through SEM and Fig. 3 shows images obtained through AFM, it means that the bagasse treated in plasma enable greater efficiency enzymes in the hydrolysis process.

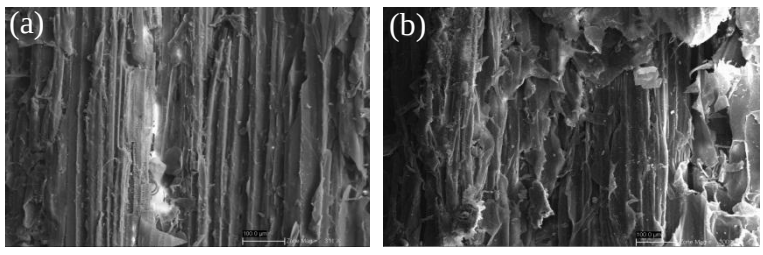

Fig.2. (a) Before water-plasma pretreatment. (b) After water-plasma pretreatment

(a) (b)

Fig.3. (a) Before water-plasma pretreatment. (b) After water-plasma pretreatment. (Z=100 nm/div)

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The Effect of Pretreatments on Enzymatic Hydrolysis of Sugarcane Bagasse: Can Plasma Overcome the Recalcitrance of Biomass?

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Introduction

Lignocellulosic materials (LM) are the most abundant source of renewable raw material to substitute fossil oil and gas in the edge of a new chemical and material industry. Lignocellulosic materials are composed mainly by an intricate arrangement of the polymeric structures cellulose (40-50% w/w), hemicellulose (30-40% w/w) and lignin (10-30% w/w/) whose components content varied with biomass origin and species. Production of bagasse and leaves from sugar cane amounts to over 40 million tons per season in Brazil. This material has been recognized worldwide as one of the most important lignocellulosic wastes for use in second generation bioethanol production and other chemicals. In Brazil, this could lead to an increase in ethanol production by around 40%, for the same area of sugar cane crop [1].

Therefore the use of this potential bio-material must be regard as strategic and in fact its exploitation has being study in various institutes and universities all over the country. Cellulose is the larger amount component in the biomass and is constituted by a high molecular weight homopolymer chain of stable β-1, 4 linked D-glucose units. Each chain is also stabilized by intra and intermolecular hydrogen bonds forming a packed arrangement of microfibrils. Hemicellulose is formed by polymerized carbohydrates most of than xylose and arabinose in the case of sugarcane bagasse (SCB) and lignin is a phenyl propane macromolecule that impairs enzymatic hydrolysis. The cellulose microfibrils arrangement is encapsulated by hemicellulose and lignin forming a tight and recalcitrant arrangement [2]. This arrangement brings to LM and particularly SCB a very high resistance to be decomposed in its monomers units [3].

The complete breakdowns of plant biomass necessitate a set of celullolytic and hemicellulotic enzymes [4]. However, the accessibility of cellulases and hemicellulase complex is impaired by the tight biomass structure. In order to disorganize this structure aiming to the access of cellulolytic enzymes is common practice to undertake physical and chemical pretreatment (PT) of LM before enzymatic hydrolysis. These pretreatments are mainly based on high temperature (above 100^{o}C) and acid catalysis (H_2SO_4, H_3PO_4) [5] and removal of lignin with NaOH [6]. However these methods are quite expensive and alternative pretreatment has being proposed. For instance, the use of plasma might be a potential applicable method of PT however only a few examples have being found in the literature [7].

Pretreatment and enzymatic hydrolysis

Pretreatment by hot water and steam at different conditions was performed resulting in SCB fibers that were used to run hydrolysis. Fig. 1 shows two images, the left one is SCB after hydrolysis and the right image is a plot from SCB analyzed by Energy dispersion Xray in pink area. The spectrum shows chemical elements after hydrolysis.

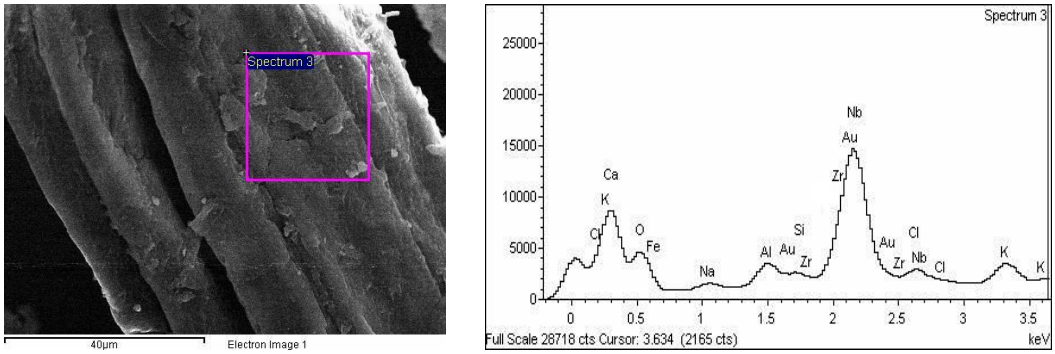

Fig.1. SEM image of arrangement of SCB fiber sugarcane bagasse after steam at 205°C followed NaOH pretreatment and enzymatic hydrolysis

It should be pointed out that the remaining metals in the pretreated SCB fibers (K, Ca, Al) are probably cations form sugarcane metabolism and that Fe was coming from sugarcane milling process. The presence of these metals on the pretreated SCB might influence enzymatic hydrolysis although this point has never been raised in the literature. Enzyme hydrolysis of some this material was performed and different carbohydrates profile was obtained (Fig. 2). High carbohydrate recovery was probably attained with depolimerization of hemicellulose due to hot water plus H_2SO_4 pretreatment followed by NaOH lignin removal. Conversely 190° C water pretreatment did not remove lignin but was able to partially depolimerize hemicellulose leading to a much higher hydrolysis than *in natura* bagasse.

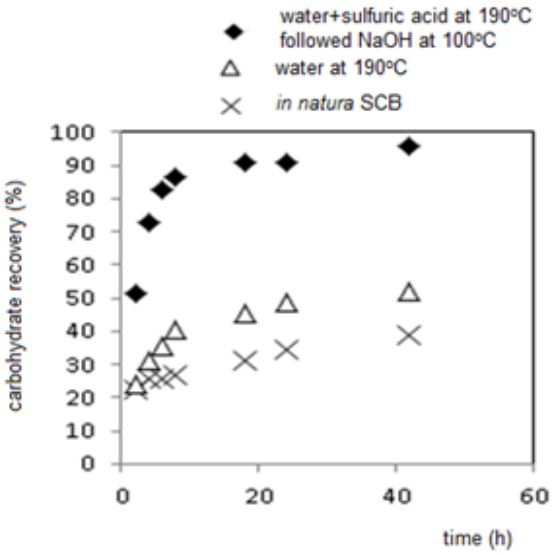

Fig.2. Carbohydrate recovery from pretreated SCB during enzymatic hydrolysis (3% total solids w/v; enzyme load at 15 FPU/ g solids; 50°C; pH 5.0)

Water + sulfuric acid at high temperature are known to remove almost completely the hemicellulose fraction form SCB and hot NaOH solubilizes about 70% of lignin from the biomass. These probably rendered to cellulolytic enzymes access to permit fiber hydrolysis and carbohydrate recovery of about 100% of carbohydrate form SCB (Fig 3). On the other hand the PT with hot water at 190°C removed bout 60% of hemicellulose from SCB left behind the total amount of lignin. As compared with the *in natura* SCB it was observed a small increment in carbohydrate recovery, from 35% to 50% (Fig 3). Therefore it is believed that enzyme accessibility was benefited by the harshest pretreatment (water + H_2SO_4 at 190°C followed partial removal of lignin with NaOH at 100°C). However, hose are costly and not sustainable pretreatment.

Encouraged by literature results [7], plasma SCB pretreatment studies have being performed at UNIVAP Nanotechplasma Research Group and preliminary results with subsequent fiber examination with AFM was carried out (Fig 3). The images revealed a very organized structure of cellulose microfibrils bundle, as described in the literature [2], [3]. It is worth to note that *in natura* SCB fibers (Fig 3a, right) seem to be recovered probably with the hemicellulose/lignin structures as proposed in literature [2], [3]. Because of the "cleaner" aspect (Fig 3.b, left) it was hypothesized that in some way there was at least a partial removal

of hemicellulose and/or lignin from SCB fiber. Enzymatic hydrolysis experiments will be performed in order to access the potential of this pretreatment method.

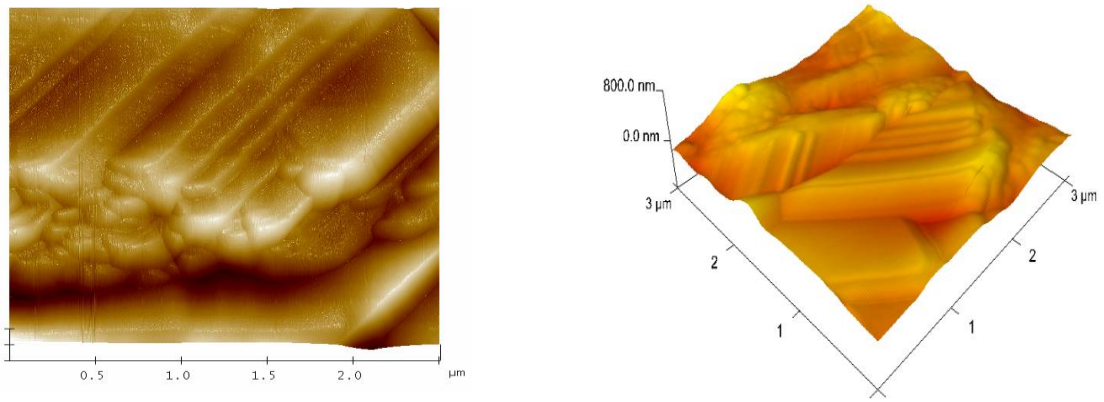

Fig.3. AFM image from in natura SCB (left) and after electric plasma with atmospheric oxygen SCB pretreatment (right)

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New Trends in the Electron-Beam Plasmas. Review of the Newly Developed Devices and Areas of the Electron-Beam Plasmas Application

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During a long time application of accelerated electron fluxes was connected with electron – beam processing of materials, plasma-chemical impact on gases and destruction of toxic materials, applications in non-selfmaintained discharges of powerful lasers, that was connected with effective excitation of electronic and vibrationally excited states of molecules. Later electron-beam plasma was investigated for revealing of elementary processes in it and search of experimental means to study them [1]. Typical scheme of these installations is represented in Fig. 1 [2]. The capability of this device to produce electron beam plasmas allowed to use it at cleaning of flue gases from SO_2 and NO_x components with an efficiency comparable with the streamer corona discharges corona. These devices recently were applied in solution of plasma combustion problems [2] at the adjustment of a combustion chamber for irradiation of a fuel. They have demonstrated applicability of electron-beam plasmas in the fuel activation.

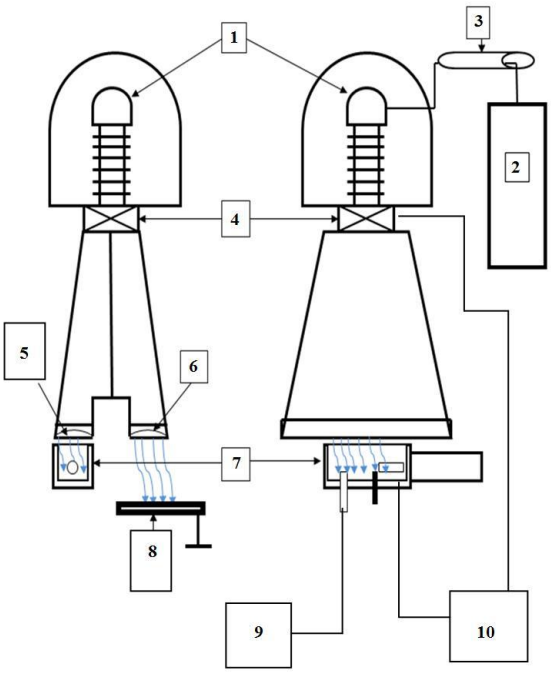

Fig.1. Functioning scheme of electron accelerator:
1 - Direct action accelerator with thermal emission cathode. 2 - High voltage rectifier. 3- High voltage connecting wire. 4 - Scanning system of the E-beam. 5 - Vacuum window for E-beam ejection into the experimental chamber. 6 - Vacuum window for E-beam continuous ejection at accelerator work. 7 - Experimental chamber. 8 - Current receiver of the working beam

Another type of electron – beams development was connected with creation of concentrated electron beams [3,4] which allowed to realize effective plasma impact on gases, and materials (nitriding and cellulose processing). Development of these devices has lead to creation of compact devices [4] and a hybrid reactor, which typical scheme is represented in Fig. 2. Recently this reactor was applied in solution of plasma aerodynamic problems [5].

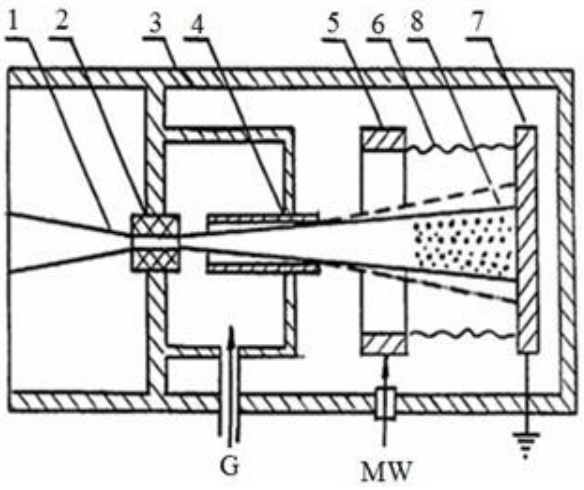

Fig.2. Hybrid reactor [1]. 1 - an electron beam, 2 - an outlet delivery device, 3- a working chamber, 4-a nozzle device, 5 - a ring electrode, 6 - an area of the gas discharge, 7- a grounded electrode, 8 - an area of the gas combined excitation. G-gas, MW- microwave power

Works on application of electron -beam and non-selfmaintained discharge plasmas show their high efficiency for solution of different applied problems. However, one of the main obstacles of these devices application is their large sizes and difficulties of maintenance. These difficulties could be overcome at applications of MW power sources [1]. Such devices have been already developed and manufactured [6]. The electron beam of the gun is brought out through a thin titanium foil across a rather large area without using any beam sweeping devices. Vacuum-tight, reliable output windows have been made. Electron optical systems generating broad beams based on the application of round ribbon and multi-tip cathodes have been developed. The electron sealed off guns are used without any vacuum pumps, they are reliable and convenient in operation. Their parameters are represented in Table1.

Electron energy	100÷200 keV
Max. pulse power of extracted beam	300 kW
Irradiation area	200×100 mm
Max. dose rate of electron beam	10 kGy/sec
Max. pulse dose rate of electron beam	5×10^4 kGy/sec
Max. radiation dose outside the case	0.2 mGy/hour
Max. power consumed	2 kW
Overall dimensions (w/o computer)	2×0.7×0.7 m
Overall weight	700 kg

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Theoretical Investigations of a Multistage Plasma Coal Vortex Gasifier

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Low-grade coal gasification is a prospective source of the universal gaseous fuel named synthesis gas [1]-[5]. Plasma coal gasification (PCG) is one of alternative gasification technologies. On the first stages of the PCG development it may better fit portable and small to mid-size coal processing facilities. There are two most critical parameters, which effect the PCG feasibility, as (1) specific power consumption as a ratio of consumed electrical power to total thermal power output and (2) duration of a plasma system non-stop operation. To minimize power consumption of the plasma system, a multi-stage muffle type gasifier was selected.

Main objective of the present work is theoretical investigation of the working processes in a multistage plasma coal gasifier using three dimensional (3-D) computing codes ANSYS Fluent. Three most reasonable oxidants for the plasma gasification process were selected based on the earlier investigations: air, oxygen, and oxygen + steam.

It was supposed that the products of gasification of various coal morphological compositions are in thermodynamic equilibrium. Calculations of the thermodynamic systems equilibrium composition were performed using software TERRA [6]. An oxidizer mass flow varied within the limit relevant to change the oxidizer excess coefficient λ in a mixture from 0.1 (coal rich mixture) to 1.0 (stoichiometry). The gasification pressure is 0.1 MPa.

In all estimations the plasma jet heat power was 50 kW with averaged temperature in the exit nozzle equal to 4500 K. Initial temperature of air and oxygen was 300 K, steam temperature - 400 K. Elementary compositions of two different coals with the relevant ash-content of 40 and 24%, humidity of 5 and 18% were introduced by the following integral formula:

$C_{40.9624}H_{29.7648}N_{0.6425}O_{16.5335}S_{0.1336}Si_{4.3272}Al_{1.8831}Fe_{0.2755}Ca_{0.1427}Mg_{0.0695}Ti_{0.0451}Na_{0.0452}K_{0.0297}P_{0.0225}$

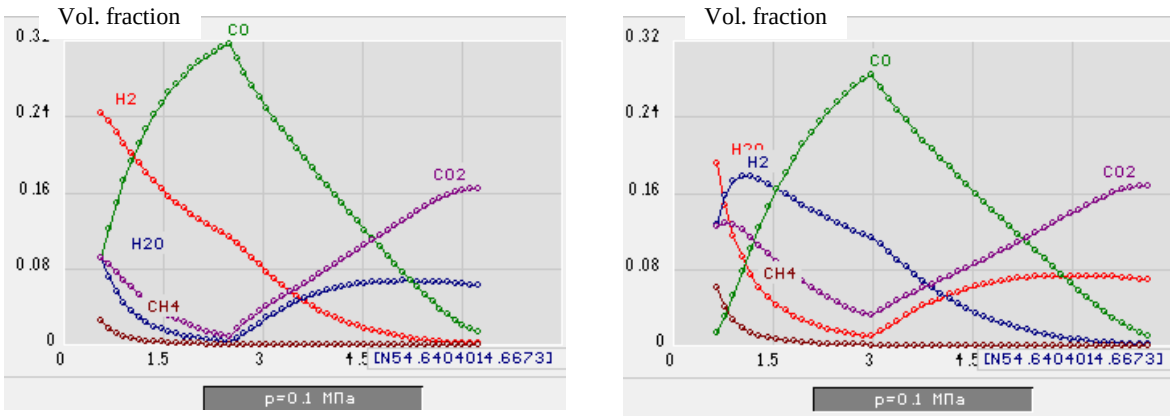
(option 1) and

$C_{47.5577}H_{37.7021}N_{1.3283}O_{15.3192}S_{0.2678}Si_{2.2635}Al_{1.0956}Fe_{0.1870}Ca_{0.2086}Mg_{0.2026}Ti_{0.0342}$ (option 2).

The oxidizer mass content for air ($N_{54.6404}O_{14.6673}$), oxygen (O_2), and steam ($H_{110.2292}O_{55.598}$) relevantly are represented along the ordinate axis on the diagrams of plasma gasification products composition (Fig. 1-3).

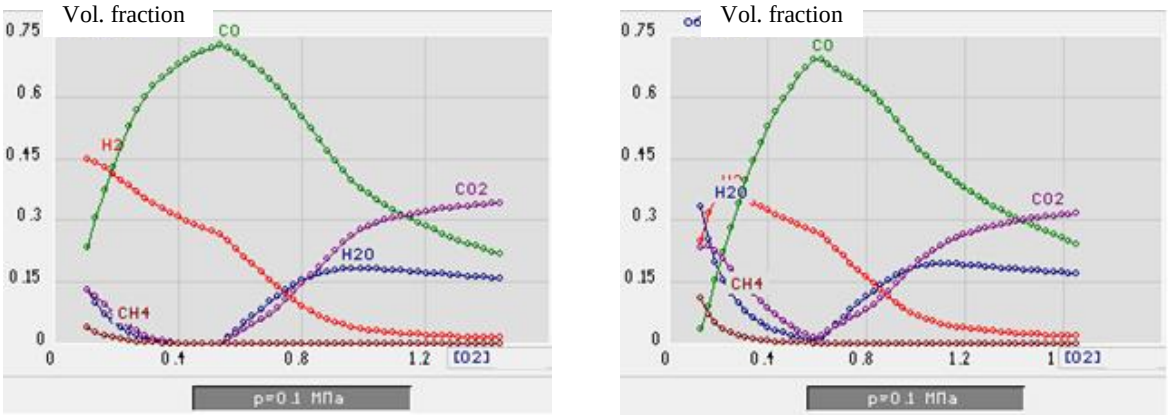
As a result, the most feasible methods of investigated coals processing are plasma oxygen and oxygen-steam gasification, which determine maximum output of molecular hydrogen and carbon monoxide. Maximum output of the molecular hydrogen is noticed for the mixtures

enriched by coal and the oxidizer excess coefficient 0.1. The maximum of carbon monoxide content takes place at the oxidizer excess coefficient 0.4-0.5.



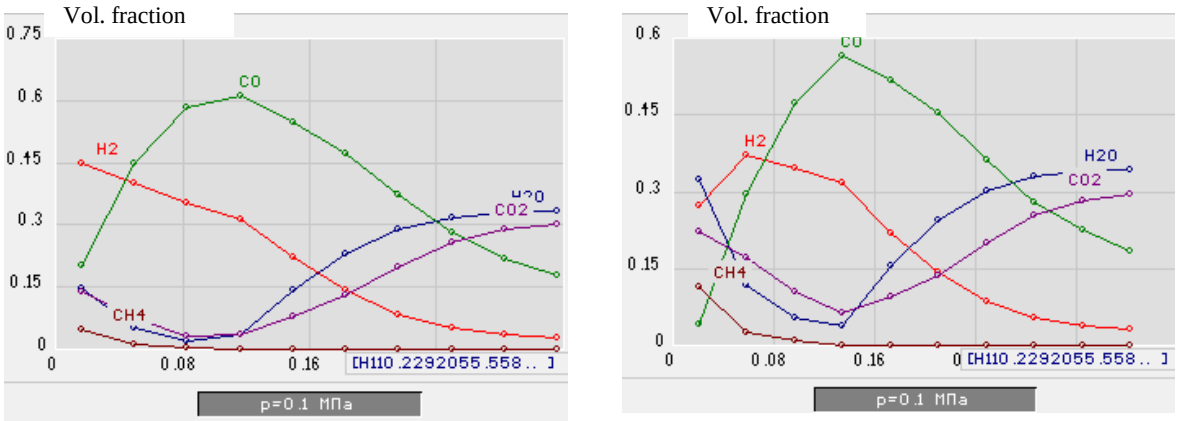
(a) (b)

Fig.1. The volume fraction of components for the air plasma coal gasification: a – option 1; b – option 2



(a) (b)

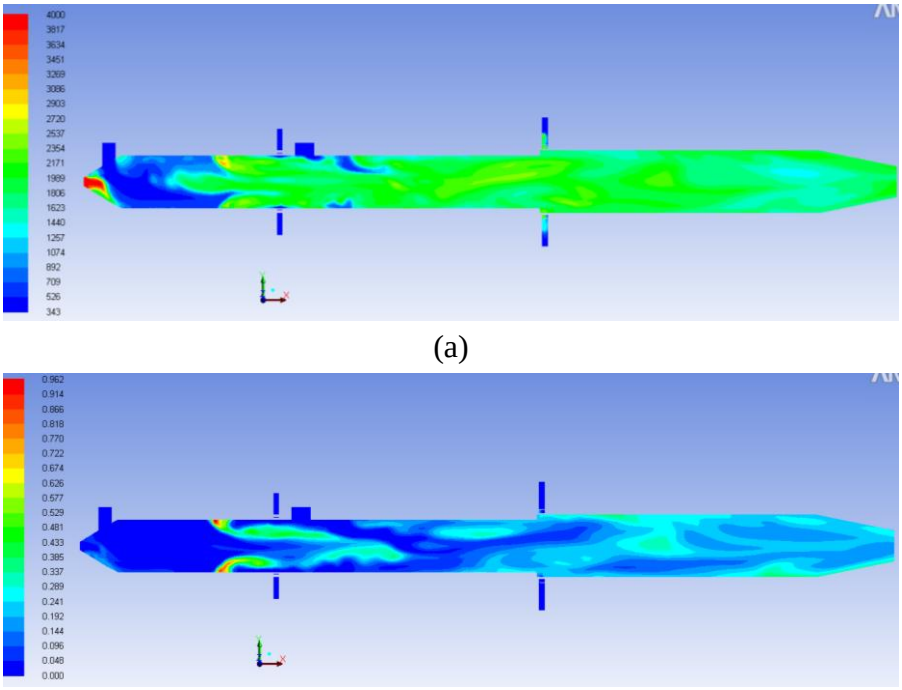
Fig.2. Volumetric fraction of components for the oxygen coal gasification: a – option 1; b – option 2



(a) (b)

Fig.3. Volumetric fraction of components for the oxygen-steam coal gasification (mass fraction of $H_2O/(H_2O+O_2)$=0.20): a – option 1; b – option 2

Preliminary 3-D modeling of the processes in the multistage gasifier with coal consumption 150 kg/h and total air excess coefficient 0.4 has been conducted. Distribution of the temperatures and the carbon monoxide concentration in the gasifier volume are shown in Fig. 4 and the main parameters at the gasifier's exit cross-section are provided in Table 1.



(a)

(b)

Fig.4. The contours of temperature (a) and CO mass fraction (b) in the gasifier cross-sections

Table 1. The main parameters in the exit cross section

Air excess coefficient λ	0.4026
Temperature, K	1915.4
Mole fraction of volatile, %	3.81
Mole fraction of O_2, %	0
Mole fraction of CO_2, %	3.73
Mole fraction of H_2O, %	7.13
Mole fraction of CO, %	21.39
Mole fraction of H_2, %	13.44

Performed calculations prove a possibility to use the 3-D computational fluid dynamics complexes in order to predict the main parameters of the plasma coal gasifier. Developed

mathematical models are planned to be used for the gasifier geometry optimization and further prototyping.

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Plasma-Fuel Systems for Energy Efficiency of Coal-Fired Thermal Power Plants

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This paper presents the results of research and application of direct-flow, vortex and muffle plasma-fuel systems (PFS) for coal-fired boilers of thermal power plants (TPP) at Ust-Kamenogorsk, Shakhtinsk, and Almaty (TPP-2 and TPP-3) (Kazakhstan). PFS are investigated for boilers with pulverizing systems with direct injection of dust (Shakhtinsk TPP and Almaty TPP-2) and intermediate bunker (Ust-Kamenogorsk TPP and Almaty TPP-3) [1], [2].

The technology of plasma ignition of coal and its realizing PFS is electro- thermo-chemical preparation of fuel to burning (ETCPF). In this technology pulverized coal is replaced traditionally used for the boiler start up and pulverized coal flame stabilization fuel oil or natural gas. Part of the coal/air mixture is fed into the PFS where the plasma-flame from plasmatron, having a locally high concentration of energy, induces gasification of the coal and partial oxidation of the char carbon. As coal/air mixture is deficient in oxygen, the carbon being mainly oxidized to carbon monoxide. As a result, a highly reactive fuel (HRF) composed of mixture of combustible gases (at a temperature of about 1300 K) and partially oxidized char particles is obtained at the exit of the PFS. On entry to the furnace, this HRF is easily ignited.

For instance, 75 ton steam productivity boiler of Ust-Kamenogorsk TPP has three main pulverized coal turbulent burners and two kindling muffle burners. The last two were transformed to PFS. Kuznetsk bituminous coal of 17.7 % ash content and 4878 kcal/kg calorific value was incinerated in the boiler. During the PFS tests at this boiler the pulverized coal flow through each PFS was 1.5 t/h and the primary air - 2.6 t/h. The pulverized coal flow through the main burners was 11.5 t/h. Plasmatron power was varied from 60 to 70 kW and its heat efficiency was 85-86 %. HRF flame temperature at the PFS exit was in interval 1040-1240^{O}C. Plasmatron's relative power consumptions were 0.5 – 0.7 % of the muffle burner heat power. NOx concentration on the PFS exit was not more than 20 mg/Nm^3 and synthesis gas ($CO+H_2$) yield exceeded 60 %. In 35 minutes of the PFS start stationary heat regime of the muffle burner was achieved, plasmatrons were turned off and heated muffles went on stabilizing the flame combustion. The flames from muffle burners were 3 m in length. The boiler oil-free start-up lasted 3.25 h after which the boiler was linked up with the main steam pipeline of the TPP.

75 ton steam productivity boiler of Shakhtinsk TPP has four burners, two on the front and rear in one layer. Bituminous coal of 30% ash content with the flow through the burner (or PFS) 3200 kg/h is incinerated in the boiler. Primary air flow through the burner is 6400 kg/h, plasmatron power is 200 kW and PFS length is 2.3 m. Numerical modeling of the ETCPF in PFS is performed using a one-dimensional mathematical model Plasma-Coal. The calculation results allowed defining the geometric dimensions of PFS, the required power of plasmatron, temperature, velocity and composition of the products of ETCPF (Table 1). These results were used as initial conditions for numerical simulation of HRF combustion in the boiler

furnace using Cinar ICE code. 3D modeling results showed that when operating PFS ignition of pulverized coal flame starts earlier, the combustion front moves to the installation location of the PFS on the boiler, resulting in lower temperature of the exhaust gases, the concentration of nitrogen oxides in them and unburned carbon, compared with the traditional mode of coal incineration without plasma activation in PFS.

Table 1. Composition of the products of ETCPF

Gas phase composition (vol.% & kg/h)								**Ash, kg/h**	**Carbon, kg/h**
H_2	CO	CH_4	C_6H_6	CO_2	H_2O	N_2	O_2		
14.2	18.4	0.3	0.6	6.8	2.9	56.4	0.3	1123.2	816.0
88.5	1599.0	14.0	133.8	931.2	162.8	4911	31.0		
Gas temperature (^OC)			Solids temperature (^OC)			Flow velocity (m/s)			
1000			1000			189.4			

The calculations of the boiler operating in traditional mode showed that four symmetrical flames with maximum temperature 1852^{O}C form a joint core at about 1300^{O}C in the central area of the furnace. Influence of PFS appears to change the HRF flame shape, increasing its length and maximum temperature to 2102^{O}C. When operating four TCP flame length increases even more, the maximum temperature is reduced to 1930^{O}C. According the modeling design of the boiler equipping with PFS for fuel-oil free start up and pulverized coal flame stabilization was performed.

Almaty TPP-3 boiler of 160 t/h steam productivity has four coal-fired blocks of two-layer slot burners. Consumption of 45 % ash content and 3800 kcal/kg calorific value Ekibastuz bituminous coal was 4 t/h through each burner. Two PFS were installed in the lower layer of the burners diagonally. Plasmatrons were running on the power of 120-140 kW (350-450 A current, and 300-350 V voltage). Ignition of the flames in the furnace was observed in 2-3 seconds after submitting of pulverized coal at a rate of up to 3 t/h through each PFS. Coal-dust flame temperature at the exit of the PFS reaches 1200-1300^{O}C, and is 5-6 m in length. Using these parameters, the formation of the bright yellow core flame in the center of the furnace was observed. In 3.5 hours from the kindling start parameters of the boiler reached operating values, and it was connected to the main steam pipeline, after which air/coal mixture was filed to all the burners. According to the rule one start-up of the boiler consumes 12 tons of fuel oil that by calorific value is equivalent to 30 tons of the coal. Instead, one start-up on average consumed about 16.5 tons of coal that confirms ETCPF energy efficiency. The specific power consumptions for plasmatrons were 1.2-1.4% of the heat capacity of pulverized coal burners.

Boiler steam productivity 420 t/h of Almaty TPP-2 is equipped with 6 vortex pulverized coal burners. Rated consumption of bituminous coal of 40 % ash content and 4000 kcal/kg calorific value is 11 t/h through one burner. 3 PFS is installed instead of the main burners. During the test the stable coal-dust flame from the PFS was obtained in the cold furnace. After ignition flame temperature reached 1050-1070^{O}C. The rate of rise of hot air temperature was about 1.5 degree per minute which corresponds to the rate of temperature rise during fuel oil boiler start-up.

Simulation and testing of PFS at existing coal-fired boilers of TPP confirmed the technical feasibility, environmental and energy efficiency of fuel oil free boilers start-up and pulverized coal flame stabilization using PFS.

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Vitrification of Hazardous Fly Ash Resulting from Incineration Plants

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We live in profound social, economic and environmental: new products are launched and new materials have been developed through technological innovation, especially in the last two decades. Concomitantly, there was a large population increase in the last two decades, especially in large urban centers and also due to economic growth, therefore there is a significant increase in consumption for goods and services.

One consequence of this growth is the increase in waste generation, as observed in surveys of public agencies and institutions such as class Brazilian Association of Public Cleaning and Special Waste - ABRELPE that, since 2003, has been conducting market research, [1]. The volume of all this waste shall have a destination, usually waste lands in Brazil. Nevertheless, given the high volume of waste generated and availability projected for waste lands in the country, it needs to be changed, because just burying waste on the ground creates additional problems for local community and this solution must be stopped by 2014, as recommended in the new national policy on solid waste and subsequent regulations. [2], [3].

Since current technologies intended to deal with waste do not mitigate the problem satisfactorily, because at the end they create new raw materials, these solutions have become obsolete and ineffective. Residues incineration in a proper plant is an usual, well known, and suitable solution from economic and environmental point of view, but it does generates fly ash with high concentration of toxic materials. [4], [5].

Waste treatment by plasma, being fly ash, Municipal Solid Waste (MSW), industrial, hospital, and sewage sludge, is shown as the best solution currently being deployed from environmental standpoint. This technology solution is commercially proven since 2002 with the first plasma gasification plant for treating municipal solid waste and industrial in Japan and has been developing ever since with more than 50 plants under engineering and construction in the United States, Canada, England Australia, India, and China. [6]-[10].

This study verifies residue issue from the perspective of thermal treatment plants and it is intended to solve their hazardous waste (fly ash) with thermal plasma. The proposed solution is new in Brazil and follows the global trend, solve current and future environmental and social problems, resulting in technological innovation and jobs in high value-added sector and finally, but not least, presents economical sustainability even in a conservative scenario. [11]-[19].

The objective of the project founded by Banco Nacional de Desenvolvimento Econômico e Social (BNDES) and conducted in the campus of Universidade do Vale do Paraíba

(Univap) is to develop a pilot reactor for the vitrification of hazardous fly ash resulting from incineration plants with a capacity for 50 kg ash / h using twin torch thermal plasma. The proposed technology serves to treat ashes from any source and becomes more economically feasible as the material becomes more toxic and harmful to both environment and people. The development of a plant for Vitrification, as presented here, is innovative in Brazil.

Companies that build thermal plants for waste treatment forget to highlight the hazards of fly ash. The lack of clarity, however, it is easily understandable, since, on one hand, there are landfills with sufficient control to receive this poisonous material and, on the other hand, the volume of hazardous ash volume generated is much lower than the garbage that was used to generate them (about 2-3% of the waste mass will become fly ash). As an example, consider a city with 600 thousand inhabitants and all its trash being treated in a thermal power plant; it will generate about 14 tons per day of ash with high concentrations of heavy metals and carcinogenic elements (dioxins and furans). It does not matter actually how small it is in comparison with previous amount of waste and one puts growing risks in perspective.

What motivates the creation of a plant capable of treating these fly ashes shows up when you put some facts in perspective. A city like São José dos Campos generates about 500 tons of garbage per day, if they are treated in a thermal power plant, they will generate about 14 tons per day of ash with carcinogenic elements that should be concentrated and loaded onto trucks, transit through streets, avenues and roads until they find a suitable landfill that will work efficiently for decades. The risk of leakage and loss of human lives and damage to the environment is unnecessary, since a technically and economically viable solution can be developed.

Table 1. Residues from thermal treatment of 500 ton/day of MSW

Residues	Generation, kg/ton MSW	Generation, ton/day	Percentage, %	Note
Bottom ash	189	94	87	Metal Recycling and possible use in construction
Fly ash	28	**14**	13	Disposal in Landfills
Total	**217**		**100,0**	

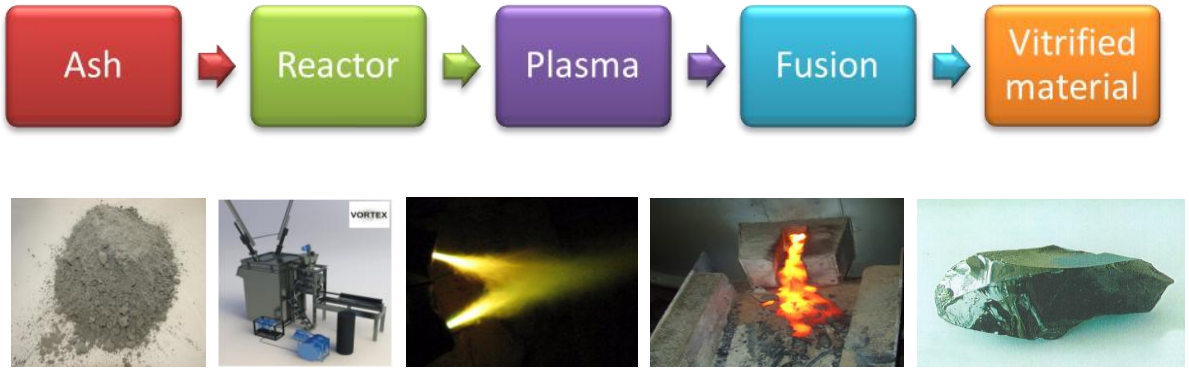

Fig.1. Diagram of the proposed pilot plant with twin torch for greater energy efficiency. Two torches are displayed, the position adjustment system of the torches (angle and height), ash inlet and melted material

This project aims to develop a pilot plant able to vitrify fly ash resulting from incineration plants of municipal solid waste through the development of a pilot reactor with a plasma transferred arc. Fig. 1 shows the process target schematically.

A comparative analysis of techniques for treatment of industrial waste ash shows that the most reliable option is vitrification, because it ensures long-term fixation of heavy metals and thermal destruction of dioxins and furans during process. The power consumption due to the vitrification of the material is in the range between 0.7 to 1.5 kW.h / kg of fly ash, indicating its feasibility.

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Thermochemical Assessment of Gasification Process Efficiency of Biofuels Industry Wastes with Different Plasma Oxidants

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A large number of technologies for the plasma gasification of industrial hydrocarbon-based, MSW and biomass waste are currently in the commercialization stage in many regions of the world. Consequently the market potential of the plants for plasma "waste to energy" gasification will grow for next period. Joint project of WPC and "Geoplasma" for Florida, US, is the example of middle-scale productivity facilities (up to 600 tons/day) for gasification of the solid wastes.

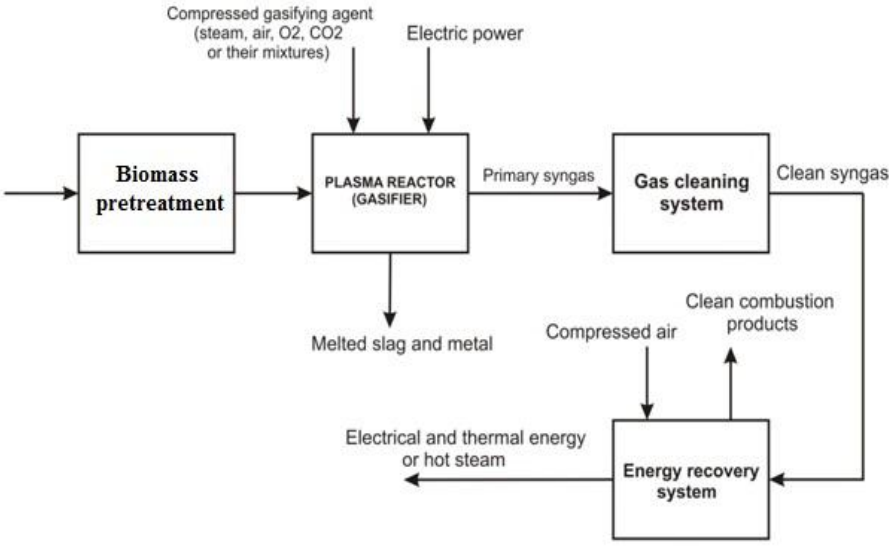


Fig.1. Principal schematic of gasification pilot plant for case of treating wet organic wastes in thermal plasma reactor [1]

This investigation was focused on the approximate thermochemical assessment of potential applications of thermal plasma gasification process [1-3] for such prospective kind of industrial feedstock, as the production of wastes of biofuels from sugar cane bagasse [4]. This assessment was realized for the bagasse (Brazilian variant) as feedstock and different variants of oxidants/gasifying agents. TERRA software code was used [2] for calculation of phase and chemical composition as well as properties at wide temperature range 300–4000 K and for pressure P = 0.1 MPa. Methodology used in this work has been recently successfully tested for the calculation of steam and air thermal plasma gasification of Brazilian and other grades of coal and related mineral feedstock [2-3]. The TERRA (version 5.3) is multipurpose software that allows implementation of the numerical method based on the principle of entropy maximum of insulated equilibrated thermodynamic systems with any elemental composition.

Besides the thermodynamic assessment of chemical composition of syngas produced after gasification we calculated also energy efficiency e, exergy efficiency ε and the energy yield EY (i.e. multiplication coefficient of total energy yield after gasification per unit of energy consumption for heating of reacting mixture to the gasification temperature $EY = (HHV_{SG} / ECG)$, here HHV_{SG} is high calorific value of syngas, based on the dependences [1], [4]-[6]. For the calculation of energy efficiency (1) was used and for exergy efficiency - (2):

Table 1. Composition of bagasse, that used for modeling [4] HCV – high calorific value, CE – chemical exergy

Ultimate analysis of bagasse, mass %		**Ash composition**	
Moisture	0 (basic level) – 50	SiO_2	2.61
C	46.85	Al_2O_3	0.26
H	6.29	Fe_2O3	0.16
O	43.724	CaO	0.10
Ash	3.2	MgO	0.01
HCV(MJ/kg)	18.88	K_2O	0.05
CE(MJ/kg)	18.77	Na_2O	0.01

$$e = \frac{LHV_{\text{Syngas}}}{LHV_{waste} + Electricity}, \quad (1)$$

where LHV_{Syngas} is low heating value of the syngas, LHV_{waste} is the lower heating value of the waste bagasse material and Electricity is the energy consumption ECG used and

$$\varepsilon = \frac{\text{Chemical exergy}_{\text{ Syngas}}}{\text{Chemical exergy}_{\ waste} + Electricity}. \quad (2)$$

The HHV of the feedstock, including of our case of biomass waste, can be accurately predicted by S.A. Channiwala's et al. equation (3) and the equation (4) of A. Friedl et al. [7], [8]:

$$\text{HHV} = 0.3491\text{C} + 1.1783\text{H} + 0.1005\text{S} - 0.1034\text{O} - 0.0151\text{N} - 0.0211\text{A} \quad (3)$$

$$\text{HHV} = 3.55\text{C}^2 - 232\text{C} - 2{,}230\text{H} + 51.2\text{C} \times \text{H} + 131\text{N} + 20{,}600 \quad (4)$$

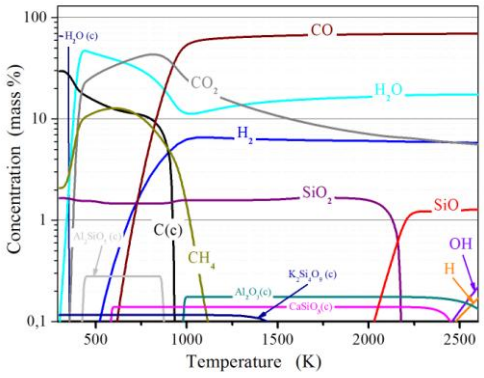
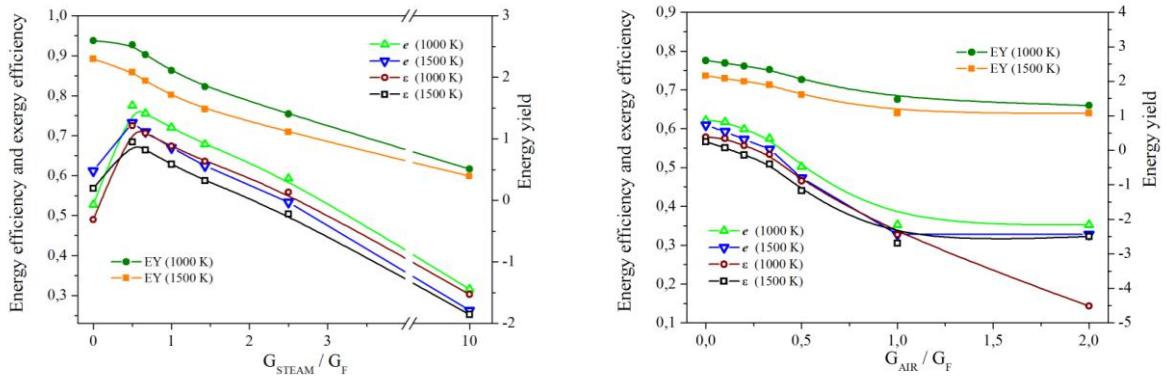


Fig. 2. Composition of gaseous and condensed phases vs. temperature for bagasse+steam gasification optimal regime (P= 1 bar) at ratio G_{STEAM}/G_F = 0.5

Based on the data calculated (Fig. 2, 3) it was determined that for gasification bagasse to syngas, is more efficient to use steam gasifying agent than air gasifying agent (for air

gasification regimes the maximal level of energy efficiency is only 0,61, whilst for the steam one this maximal level is 0,77). Hereby it´s possible to recommend for use as optimal regime the mode with ratio of mass flow rates of gasifying agent to feedstock G_{STEAM}/G_F = 0.5 at the T = 1000 K.



(a) *(b)*

Fig. 3. Energy and exergy efficiency of produced syngas and its EY vs. the ratio of mass flow rates of gasified agent to feedstock (a) G_{STEAM}/G_F and (b) G_{AIR}/G_F

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Thermoplastic Waste Processinginto the Alternative Liquid Fuels

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Abstract

The scientific team both National University of Shipbuilding and R&D Company "Energy & Technology" has researched, designed and developed the advanced technology for thermoplastic waste processing into the alternative liquid fuels. The primary raw material for processing is the mixture of unsorted thermoplastics. The results of processing are the following commercial alternative fuels: gasoline, light diesel oil, heavy diesel oil, and heavy boiler's oil. A small amount of carbon black and (3…5%, approximately) and passing gas mixture (2…5%, approximately) are the rest of the processing. Carbon black can be used as admixture into asphalt cover for highways. A part of heavy diesel oil, total amount of the heavy boiler's oil and passing gas mixture are used as energy source for processing.

Introduction

At present time plastic's waste in huge amount are thrown out and pollute an Environment. For instance, in the Ukraine annually forms up to 1,000,000 tons of plastic's waste, in Germany – up to 8,000,000 tons, in Austria – up to 3,000,000 tons. In US and Canada this amount approaches 31 million tons, approximately and in Canada – 14 million tons, accordantly. This waste does not self-destroyed within a long time and requires technical facilities for their neutralizations. Especially dangerous is medical plastic waste which contaminated by biological hazards.

Simultaneously plastic waste is the mixture of the hydrocarbon's substances, which can be processed into the useful commercial fuels [1].

The special an experimental facility capacity of 300 kg per day has created in the Center of the Advanced Energy Technology (Fig.3.). Its principle scheme is sown on Fig.4. The main goals of this facility are to obtain processing operation parameters, yield of the artificial fuels and their quality, and passing products, as well. Processing facility has passed the complex tests and main technical, technological and operation parameters were obtained. The ecological and environment protection criteria were determined as well.

Fig.1. An experimental facility for thermoplastic waste processing into artificial fuels

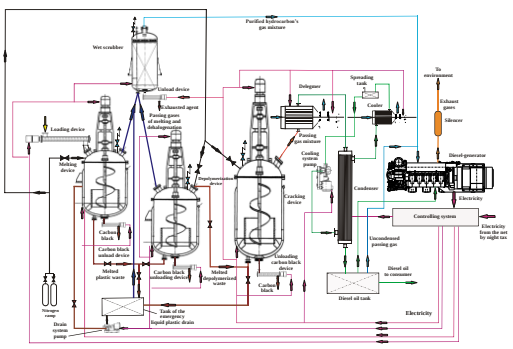

Fig.2. The principal scheme of the experimental facility

The main principle of this technology is continuous and controlled thermo-cracking process without air (oxygen) access. It allows receive complicated artificial organic liquid, which includes hydrocarbons mixture of wide light fraction. After cracking, distillation and rectification, alternative gasoline and diesel oil can be produced. The technology can be adapted for the receiving mainly one of named fuels, as customer will apply. Processing equipment doesn't require energy carriers from outside, except starting operation. A small amount (7…15%) from produced fuel is using for processing energy supply.

The experimental facility operates during a half of year with different thermoplastic raw materials including PE, PP, PS, ABS, PET, PVC [2], [3]. The experimental facility product's output (%), approximately, depending on tuning is the following (Table 1):

Table 1. The experimental facility product's output (%).

	Gasoline	Light Diesel Oil	Heavy Diesel Oil	Heavy Boiler's Oil	Passing Gas Mixture	Hard Remainer	Total	Process Supply[1]
Version I	45,4	15,2	8,5	6,1	15,5	9,3	100,0	10,7
Version II	25,2	32,7	13,1	8,6	12,3	8,1	100,0	9,2
Version III	13,1	52,2	16,7	9,2	4,5	4,3	100,0	6,3

[1] – %, from total product's yield (heavy boiler's & passing gas)

Processing technology is friendly to the Environment. The results of ecological, sanitary and hygienic investigation have defined. Content of the harmful substances doesn't exceed 30 % from maximum-permissible concentration into air of the operation area [4].

A small pollution provided by systems for chemical dehalogenation and final treating of the exhaust gases with advanced plasma technology elaborated and supplied by Applied Plasma Technologies (APT) Corporation.

The project of the thermoplastic waste processing plant capacity of 35,000 t/year has designed on the base of the researches, tests and operation experience.

Table 2. Average main project indexes

##	Indexes	Value
1	Capacity of the plastics waste processing, t/year	35.000
2	Gasoline, t/year	5250
3	Light diesel fuel, t/year	19250
4	Heavy diesel fuel, t/year	6650
5	Hard remainder, t/year	1400

The main advantages of the alternative fuels from the thermoplastic waste are the following: ultra-low sulfur content, low heavy metals and paraffin content, low total contamination, good oxidation stability and copper strip corrosion, low cold filter plugging and cloud points.

Fragments of an experimental plant are shown on Fig.3, 4 and explication – on Fig.5.

Fig.3. Processing devices and refining columns

Fig.4. Artificial fuel tanks

Conclusion

Plastic waste technology processing into the artificial fuels that was developed in Advanced Energy Technologies Center is energy efficient and ecologically safe. Experimental research and test-mode operation allow us to conclude that this technology can be safely implemented for industrial purposes.

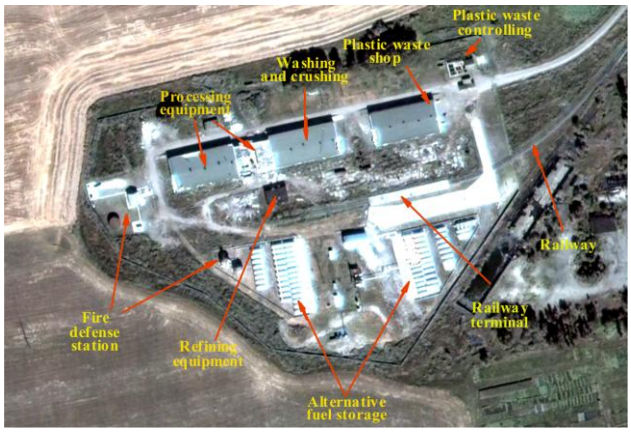

Fig.5. Explication of the experimental processing plant (Google view)

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Study of Heat Transfer in DC Transferred and Non-transferred Electric Arc Heaters for Plasma Gasification, Nanocarbons Synthesis and Related Processes

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This paper is focused on the method of generalization of results of plasma-wall heat transfer in various plasma heaters based on physical modeling of transferred and non-transferred electric arcs [1]-[3]. These plasma heaters were used by us in the reactors for gasification of organic feedstock and waste and related processes (in which injected reactants are processed). Heat transfer parameters for plasma and two-phase (plasma-feedstock) flows are necessary to be determined to design and model such processes and reactors. Theoretical analysis is complicated in this case; experimental data can be generalized in the form of local or zone equations to be used in engineering practice. Basic principles of such modeling and generalization of electric arc discharges in DC torches were developed by O. Yas'ko group and some others [3]-[4]. Independent variables for the regression generalization of current-voltage and thermal characteristics of plasma torches typically include the dimensionless numbers which take into account various mechanisms of transfer of joule dissipation energy: $\pi_{conv} = G\,d\,\sigma_0\,h_0 / I^2$ – for convection transfer, $\pi_{cond} = \sigma_0\,\lambda_0\,T_0\,d^2 / I^2$ – for conduction transfer, $\pi_{rad} = \sigma_0\,Q_0\,d^4 / I^2$ – for radiation one. In our study we propose the approach that considers plasma heater based on a few torches or/and plasma-feedstock mixing chamber (MC) as unified system. In such a case the heat transfer in MC and reactor channel is assumed to depend significantly on the processes in arc plasma torch (PT). Therefore initially hypothesized group of the dimensionless numbers characterizing heat transfer in plasma heaters may be represented as follows. This group should include the numbers, which were proposed to generalize the experiments in PTs operating with longitudinally blow arc [3-5], such as π_{conv} and π_{rad} numbers. It will be expedient to use zonal Stanton number St or $\tilde{\eta} = (1-\eta)/\eta$ as generalized function [1], [2]. $\tilde{\eta}$ is a generalized thermal efficiency (GTE), which at its small values is analogues to St number.

At first step, the generalization of thermal efficiency of DC non-transferred PTs with tubular electrodes (that can be used for alkane conversion to syngas) was performed. The data of experimental operating regimes of these torches was subjected to regression analysis based on the physical modeling. Optimal regimes were determined on the basis of this analysis. The defining criteria including convection, radiation and conduction factors were used in the following form $\pi_{conv} = I^2/(G\,d\,\sigma_0\,H_0)$. Here G, d, σ_0 and H_0 – are the plasma gas mass flow rate, output PT electrode diameter, plasma electric conductivity and its enthalpy correspondingly [5]. So, the dependence of this type GTE on operating parameters of plasma

heater used for air conversion of liquefied petroleum gas (LPG, mixture of propane and *n*-butane) was established:

$$\tilde{\eta} = 2.68\left(I^2 / Gd\right)^{-0.095}\left(G/d\right)^{-0.218}\left(1-\gamma_p\right)^{-0.36},\ \text{(multiple correlation coefficient } R = 0.79), \quad (1)$$

here G is the total mass flow rate of the gases in this DC torch type, i.e. sum of LPG and air, γ_p – mass fraction of LPG feedstock in reacting mixture with plasma gas. This dependence is correct for the following range of torch operating parameters: current I = 100–400 A, voltage U = 100–350 V, power N = 50–200 kW, plasma gases mass flow rate G_{air} = (0.5–3.5)·10^{-3} kg/s and G_{LPG} = (0.5–4.0)·10^{-3} kg/s, outlet diameter of torch anode d = 0.01–0.025 m, output pressure P = 0.1 MPa. In similar case of non-transferred arc PTs with rod cathode and tubular anode, operating with the same (air + LPG) gas mixture (that is quite efficient for MWCNT-based nanocarbon synthesis technology [5]) the generalized equation for GTE was found to be formulated as follows:

$$\tilde{\eta} = 3.02\cdot 10^6\left(I^2 / Gd\right)^{-0.8}\left(G/d\right)^{-0.71}\left(1-\gamma_p\right)^{0.39} \qquad (\text{R} = 0.97). \quad (2)$$

Next GTE dependence for thermal efficiency of twin plasma torch (TPT) was also established for the ridge as well as normal regression. TPT is a DC transferred arc plasma torch with tubular electrodes. It is considered to be highly efficient to be used in various plasma reactors for gasification and ash vitrification [6]. The established dependence can be used in engineering practice to design 80–300 kW TPT heaters:

$$\tilde{\eta} = 19.58\left(Gd\sigma_0 h_0 / I^2\right)^{-0.283}\left(\sigma_0 Q d^4 / I^2\right)^{0.106}\left(a/\left(d\sin\left(\alpha/2\right)\right)\right)^{-1.043}. \quad (3)$$

For (3) using procedure of normal regression analysis R is as high as 0.83. In addition to convection π_{conv} and radiation π_{rad} factors geometrical simplex $a/(d\sin(\alpha/2))$ was applied. At next stage triple torch heater of 100–150 kW was the object of the heat transfer study [1]. The reactor consists of cylinder MC (CyMC) with three air non-transferred PTs and axial injector of cold gas. The resultant equation on GTE of the full plasma module is

$$\tilde{\eta} = 35.4\left(I^2 / Gd\sigma_0 h_0\right)^{0.933}\left(\sigma_0 Q_0 d / I^2\right)^{0.639}\left(G_{3pl}/\left(G_{3pl}+G_{gd}\right)\right)^{2.070}, \quad (R = 0.87). \quad (4)$$

For this module the formula for St number was also found:

$$\begin{aligned}\text{St} &= q_w \pi d^2 / 4G\left(h-h_w\right) = \\ &= 0.495\left(I^2 / Gd\sigma_0 h_0\right)^{0.825}\left(\sigma_0 Q_0 d^4 / I^2\right)^{0.557}\left(G_{3pl}/\left(G_{3pl}+G_{gd}\right)\right)^{1.961},\end{aligned} \qquad (R = 0.86). \quad (5)$$

Further the regression for GTE of another plasma module (three air plasma torches and conical MC, i.e. CoMC) with zone of the reactor channel was analyzed for the modes with liquid feedstock injection. Correlation coefficient is R = 0.78 for:

$$\tilde{\eta}_{3plmcs} = 38.90\left(Gd\sigma_0 h_0 / I^2\right)^{-0.522}\left(G_{rm}/\left(G_{rm}+G_{gd}+G_{3pl}\right)\right)^{-0.169}. \quad (6)$$

In this case GTE value is affected by such independent variables as π_{conv} and mass fraction of sprayed feedstock in reacting mixture $G_{rm}/(G_{3pl}+G_{gd}+G_{rm})$. Also 100 kW reactor for the coal pyrolysis was investigated. It is based on the cylinder MC with three non-transferred PTs operating on hydrogen as plasma gas. GTE of PTs was determined:

$$\tilde{\eta}_{pl} = 674.53\left(\sigma_0\lambda_0 T_0 d^2 / I^2\right)^{2.701}\left(Gd\sigma_0 h_0 / I^2\right)^{-1.764}, \qquad \text{(R = 0.63).} \qquad (7)$$

For this type of reactor with H_2 plasma the dependence was also found for GTE of CyMC plus zone of reactor channel, under operation modes with feedstock injection, in the simple form:

$$\tilde{\eta}_{mcs} = 0.422\left(G_{rm} / \left(G_{3pl} + G_{gd} + G_{rm}\right)\right)^{-0.024}, \qquad \text{(R = 0.62).} \qquad (8)$$

Hereby the obtained equations demonstrate that heat transfer in the electric arc systems (with transferred arcs and in some cases of non-transferred ones, e.g. based on cylinder MCs) is mostly affected by convection and radiation processes in the torch arcs. It is important that the radiation heat transfer is negligible in heaters with conical MCs. For both operating regimes with and without feedstock injection the regression coefficient R for GTE of plasma module with CoMC is about 0.75–0.81. These values are lower than that for CyMC based plasma module.

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Informative Message, ICPAT-8
Water Treatment by Plasmas – Advanced Oxidation/Reduction Technologies (AO/RTs)

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Advanced oxidation processes (AOPs) were defined by Glaze *et al*. [1] in 1987 as "near ambient temperature and pressure water treatment processes which involve the generation of hydroxyl radicals in sufficient quantity to effect water purification". Hydroxyl radicals (OH) which are generated in AOP technologies are very strong and non-selective oxidants. Once generated, the hydroxyl radicals can non-selectively attack organic compounds and are capable of degrading a wide range of resistant organic compounds to ultimate mineralization to CO_2 and H_2O.

AOPs employ reactive oxidizing agents such as hydrogen peroxide (H_2O_2) or ozone (O_3), with or without addition of catalysts or photolysis. These oxidation systems have been used to treat both individual organic and inorganic substances in water under laboratory conditions as well as real effluents from the different sources.

Since 1987, the field of AOPs has been expanded to include reductive agents, such as hydrogen atoms H and solvated/aqueous electrons e_{aq}, which are generated in plasmas in water and water irradiated by electron beams [2], [3] or gamma-rays. The AOP terminology has thus been evolved into Advanced Oxidation/Reduction Technologies (AO/RTs), including aqueous-based plasma treatment of pollutants and some minerals/solids.

The field of aqueous-based plasma water treatment has a history of about two decades, starting with so-called electrohydraulic discharges (EHDs) and corona-streamer discharges which were pioneered by Clements et al [4] in the 1980s and Sun et al [5], Sunka et al [6] and Joshi and Locke et al [7] in the 1990s. An excellent review of EHDs and non-equilibrium plasmas for water treatment is given in the publication by Locke et al [8]. Additional material on aqueous-phase electrical discharges for water treatment can be found in the more-recent publication of Shih and Locke [9]. Aqueous-phase electrical discharges have been powered by DC, pulsed DC, AC and RF sources – although we will not cite references here. Additional, more-recent work on plasma formation in water has dealt with discharges in gas bubbles entrained in water [10]. This technique appears promising for practical applications.

The foundation for the above investigations was set by studies of underwater arcs (usually produced by capacitive electrical discharges in water), which considered the plasma properties of such discharges. The earliest-reported, plasma-connected research on electrical discharges in water of which these authors are aware is that contained in the 1960 publication by Martin [11]. However, for scholars and history-minded individuals, there is the 20th Century publication of 1932 by Carter and Campbell [12] that reports investigations on arc discharges in water, including descriptions of the chemical nature of the arc-produced byproducts. This publication was four years after Irving Lagmuir coined the term "plasma" to describe the glow discharges like those in a Crookes tube of the late 19th Century.

More recently, Morgan and Rosocha have carried out experiments on pulsed electrical discharges applied to saline solutions. [13]. Such investigations have shown the possibility of producing supercritical water at high temperatures and densities using a short pulse electric surface discharge in saline solutions. The electrical conductivity of an electrolyte is far greater at the liquid surface than is the bulk conductivity. A short pulse (10s – 100s ns), high voltage and current surface discharge will then ablate liquid layers, much like laser ablation, driving the ablated fluid to super critical temperatures, pressures and densities above the saturation line, as is found with exploding wires in water.

Summary

Aqueous-phase plasmas have mainly been explored in terms of water arcs (thermal plasmas) and pulsed corona discharges (non-thermal plasmas - NTPs). As is the case for air-based pollution control, NTPs are probably more effective and efficient in destroying entrained pollutants. To succeed with plasma-based water treatment, we must develop reactors that scale to large bulk-volume treatment. This will also require the development of novel power supplies and impedance matching techniques for powering plasma generation in the reactors. Pulsed DC plasma sources are required for such systems. We believe that short-pulse (10s-100s ns) pulsed power modulators (like those used for decades in high average power, repetitively-pulsed lasers) are a promising option for NTP-based water treatment systems. Such plasma-based processes will likely have an advantage over electron-beam processes in terms of capital equipment cost and radiation safety costs.

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Perspectives on the Interaction of Plasmas with Liquid Water for Water Purification

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The importance of clean water for the world's population is discussed by invoking the UN Mandate Worldwide Debate of 2010. Methods of water purification are presented with an emphasis on the use of non-equilibrium plasmas. Plasma production or plasma injection in liquid water affords one the opportunity to non-thermally inject advanced oxidation processes into water for the purpose of purification or chemical processing. Such technology could potentially revolutionize the treatment of drinking water, as well as current methods of chemical processing with plasmas to eliminate physical catalysts. Presented here is an overview of current water treatment technology, its limitations and the future, which may feature plasma-based advanced oxidation techniques. As such, this field represents an emerging and active area of research. The role that plasma-driven water chemistry can play, in addressing emerging threats to the water supply, are discussed using case study examples. Limitations of conventional plasma injection approaches include limited throughput capacity, electrode erosion, and reduced process volume. Two potential approaches designed to circumvent such issues, are being pursued through collaboration between NASA and the University of Michigan. These efforts include direct plasma injection using an underwater DBD plasma jet and the direct excitation of underwater isolated bubbles via a pulsed electric field. These approaches are presented here, along with the results.

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Water Purification by High-Voltage Nanosecond Plasma: Further Experimental Results

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The application of a fast, nanosecond pulsed discharge for the purpose of water purification with application to recycling systems as well as for terrestrial point-of-use applications in areas lacking water treatment infrastructure was investigated. A DBD plasma jet excited by a repetitively pulsed ns pulse power modulator was used to decolorize a $1.4 \cdot 10^{-4}$ M solution of Methylene Blue (MB) as a test case. Time-resolved decomposition of the MB in solution was assessed using spectrophotometry and high pressure liquid chromatography (HPLC). Spectrophotometry results were found to be in agreement with chromatography measurements. HPLC revealed the absence of appreciable intermediates suggesting high level mineralization. Acidification was also observed during processing. Also anecdotally explored was the effect of starting volume size on decomposition rates which revealed that decomposition rates fairly invariant to volume over the range investigated. The discharge apparatus efficiency was also compared as a function of two distinct methods of excitation: 1) ac sinusoidal excitation and 2) excitation via ns pulsed power modulator. Finally, the stable operation of two applicators operating in parallel was demonstrated. The dual-applicator operation was found to greatly improve decomposition times though overall decomposition efficiency remained approximately equal to that of a single applicator. Additional diagnostics were installed which allowed for fast high voltage and current signals to be measured. The frequency spectrum of the current signal was also documented as a function of applied voltage. The evolution of the discharge as a function of voltage was mapped using a video camera.

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Adherence Study of Hydrogenated Amorphous Carbon Film via Optic Sclerometry

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The objective of this paper was to evaluate the adherence of DLC films produced in AISI 304 substrates with five distinct ridges. The samples were provided by CNPq project 400766/2012-4. The DLC films were obtained by the technique of chemical deposition from the vapor phase English "Plasma Enhanced Chemical Vapor Deposition" "PECVD" according to already published procedure [1].

The adhesion strength in ceramic type materials may be defined as the work necessary in order to have the separation between atoms or molecules at the interface [2], [3]. The adhesion force may have changes at the substrate surface due to the presence of contaminants. Evaluation of adhesion strength can be made using assays such as assays scraper (scraping test), folding (bending test), impact, cavitation and printing Rockwell which are used in an attempt to measure adherence [4], [5]. The test is applicable to scratching test adherence assay on various types of hard coatings such as: ceramic materials, carbides, nitrides, oxides and diamond-like carbon, metallic or ceramic substrates. The risk sclerometry formed in the test is evaluated according to failure modes with the main mechanisms responsible for the formation of adhesion between the coating and the substrate ranked by Burnett and Rickerby [6].

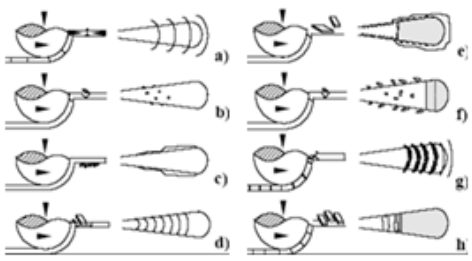


Fig.1. Summary of failure mechanisms of adhesion of the coating to the substrate. [7]

The adhesion failures cohesive nature is characterized by the formation of cracks semicircular parallel to the contact surface of the tip and towards it, with little exposure of the substrate, as can be seen in Fig 1 (a-d). If the cracks are formed, but not propagate through the signal interface is good adhesion.

Already indicative of the failure is adhesive in nature adhesion formation chips originating from the coating indicating that it is fragile and brittle, as can be seen in Fig. 1 (e-h).

Assays were performed from AISI 304 samples prepared with sandpaper grain size of 180, 320, 600, 1200 and 2000. For assay was used tribometer UMT-2 sclerometry CETR multifunctional operated in linear reciprocal [8], with the following standard tip

ASTMC1624-05 was a diamond Rockwell C type, terminal this pyramid tip with a radius of 200 and one angle of 120 degrees with load application broken down into three modes: constant, gradual and incremental.

Modes of application of load cause risks with different characteristics, as shown in Fig 2.

Fig.2. Photomicrograph obtained by optical microscopy of tracks obtained by three modes. of load, with (a) constant load, (b) progressive loading and (c) load increments

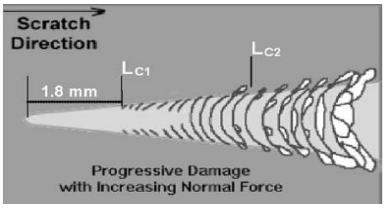


Fig. 3 Critical Scratch Load Damage Features in Progressive Load Test.[8]

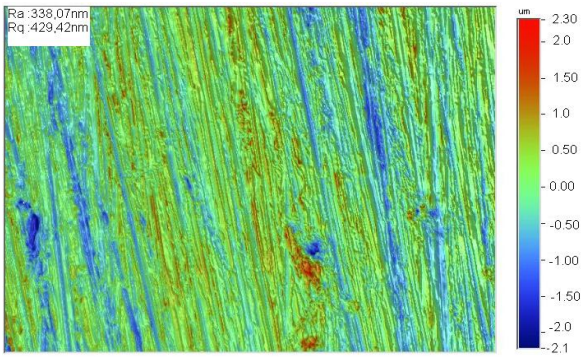
The films were analyzed through a progressive load to have greater reproducibility because the films have amorphous characteristics and therefore present greater inequality between film and substrate. Was used the load range of (1-30) N, speed 1 mm / s in the range of 8mm. The scratching test results of DLC films, in which were deposited on AISI 304, obtained from the average of three measurements performed on all grain sizes tested in directions parallel and perpendicular the track. The process of adhesion was evaluated by the values of the critical load 1 (LC1), obtained by acoustic emission of sound from the first set and also the second critical load (LC2) obtained by the sound of the sample region without film Fig 3. Results showed that the values for the sample LC1 positioned perpendicular to the trail got greater resistance to mechanical risks compared with the samples with parallel tracks metallographic risks.

The roughness was analyzed by optical microscopy. The Fig 4 shows the sample images with 180 positioned parallel of the risks following the direction of sandpaper marks. The sample was left on the roughness of Ra (roughness arithmetic) 338.07 nm and Rq (quadratic roughness) of 429.42 nm. Table I shows the relation between the granulometry of sandpaper: 180, 320, 600, 1200 and 2000 and the roughness Ra and Rq measured via optical profilometer. It can be seen in this table that the sandpaper 180 leave the surface with a roughness Ra of 338.7 ± 26.0 2000 sandpaper and the roughness Ra was 73.99 ± 6.20.

Table 1. Relationship between particle size and roughness of sandpaper produced in AISI304

Sandpaper	***Ra, nm***	***Rq, nm***
180	*338.70± 26.00*	*429.42± 38.00*
320	*262.81± 22.00*	*345.54± 29.00*
600	*222.83± 18.00*	*283.29± 26.00*
1200	*111.06± 90.00*	*146.69± 12.00*
2000	*73.99± 6.20*	*95.52± 7.60*

Fig 5 shows Raman spectra obtained using 515 nm laser in the range 800-1700cm-1. The spectra indicate the position of D band centered at 1360cm-1 and the position of G band centered at 1560cm-1. The D band indicates the clutter of links sp, sp2, sp3 of DLC films and G band indicates the graphite phase in the form of sp2 bonds in these films. It can be seen from Fig. 5 that the position center of D and G bands are displaced to the right. The rightward shift of the G band and D indicate a reduction in the number of grains of graphite phase in aromatic rings. More specifically indicates the reduction of breathing modes of ring sp2 atoms existing in and consequently a reduction in the structure of these rings DLC. The D band center at 1277cm-1 and the G band center at 1518 cm-1 in the ratio between I (D) / I (G)



301µ

Fig.4. Photomicrograph obtained via optical microscopy steel AISI 180 treated with sandpaper

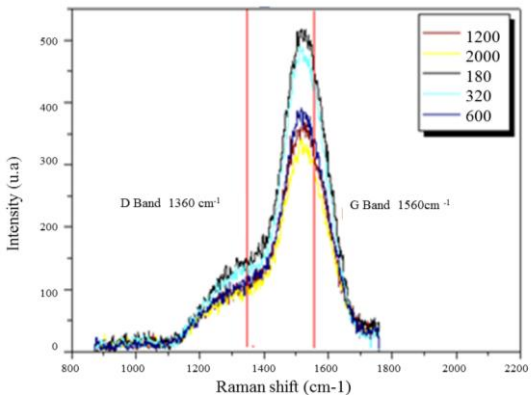
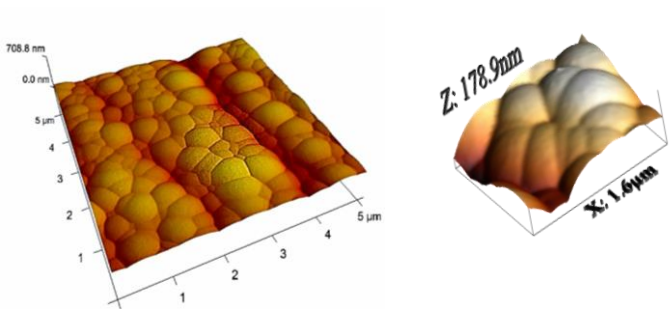


Fig.5. Raman spectra obtained using 515 nm laser in the range 200-2000cm^{-1}

bands was indicative of the structure of DLC, according to the article Cinzia Casiraghi [9] the ratio I (D) / I (G) = 1.8 indicating the formation of films of hydrogenated amorphous carbon characteristic a-C:H. The chart below shows the ratio I (D) / I (G) = 1.84. Indicating that all films are analyzed a-C:H.



(a) *(b)*

Fig.6.

(a) Image in 3d with (5x5) µmx 708 nm of DLC films on AISI 304.
(b) magnification of the same image

Fig. 6 (a) and 6 (b) shows two images obtained via atomic force microscopy of DLC films on AISI 304 polished with sandpaper 2000, and Fig. 6 is a 3D image with XY dimensions (5x5) micro and Z height was equal to 708 nm. It can be seen in this picture that the grains have a distribution packaging and that copy the steel surface. Fig. 6 (b) shows an enlargement of Fig. 6 (a) to emphasize the display dimensions of the grains and that image can be seen grains with dimensions in the range 200-300nm and below 100nm of Z height.

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She is currently studying MSc in materials processing and catalysis at the University of Paraiba Valley, participates in the group's research laboratory of nanotechnology and plasma processing (NanoTecPlasma) at research and development (IP & D), located in University Paraiba Valley, assisting in the development film deposition diamond-like carbon (DLC) for various applications, analysis of sclerometry with aim of assessing the adherence of the film on the substrate.

Plasma Treatments for Metallic Surface Modification to Obtain Highly Adherent Diamond-Like Carbon Coatings

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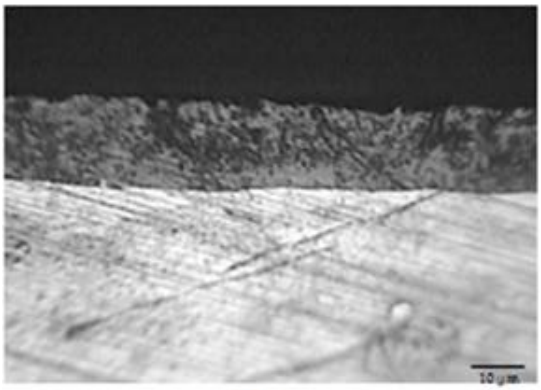
Stainless steels are widely used in the chemical industry and in food production due to their excellent resistance to corrosion and oxidation at high temperatures. However, its relatively low wear resistance and hardness limit their uses [1]. Similarly, titanium and its alloys are being used in the construction of engine parts. Much of titanium produced worldwide is being used in the aerospace industry, and no less important in industries such as chemical, energy, nuclear, and shipbuilding. In recent years, it has also increased the demand for titanium and its alloys in medicine for the manufacture of bone implants and surgical instruments. Unfortunately, titanium and its alloys also have low tribological properties [2].

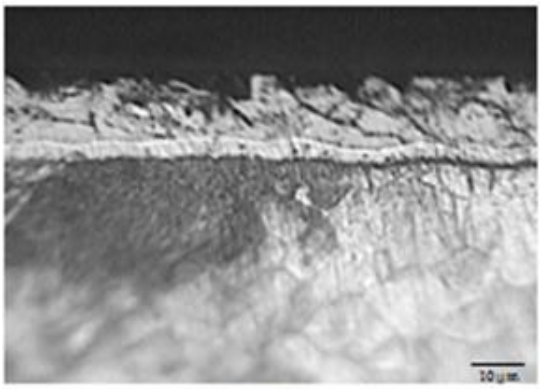
Plasma nitriding process has been the most widely used technique for treating metal surfaces due to its low cost and easy industrial application. In order to increase the quality of the nitriding process, a small amount of a carbon carrier gas such as methane (CH_4) is added to the plasma. This technique is known as carbonitriding and permits the simultaneous incorporation of carbon and nitrogen in the interface, increasing the mechanical and tribological properties of metal surfaces [3]-[6]. Although these surface treatment techniques allow to increase the tribological properties of metal surfaces, for many applications requires high surface hardness and high wear resistance. For these applications require the use of protective coatings.

Research and development of nanostructured materials with improved, tailor-designed properties is a fundamental need for the growth and advance of automotive, aerospace, chemical, biomedical and electronic industries among others. Plasma synthesis of coatings is a powerful and versatile way to obtain such materials. Among them, the family of Diamond-like Carbon (DLC) coatings stands out due to their properties: high elastic modulus and hardness, chemical inertness, low friction and high wear resistance, high thermal conductivity, biocompatibility, and also due to the possibility to tune these properties by specific settings of the plasma conditions and deposition technique.

In this work, the obtained results of the deposition of hard and adherent DLC films on four metal substrates: stainless steels AISI 304 and ASTM F138, carbon steel AISI 1020, and Ti6Al4V alloy are presented. The DLC films were deposited using a modified pulsed-DC PECVD technique [7]-[10]. With the aim to elevate the film adhesion, surface modification treatments: nitriding, carbonitriding, and carburizing were used previously to DLC film depositions.



(a)



(b)

Fig.1. Optical micrographs of cross sections of a sample of stainless steel AISI 304 nitrided (a) and carbonitrided (b) at 675 K

Fig. 1 shows optical micrographs of cross sections of a stainless steel AISI 304 sample nitrided (a) and carbonitrided (b) at 675 K. From the Fig. 1 (a) can observe that in the sample that was nitrided appear only one surface layer rich in nitrogen. The carbonitriding process produced a two-layer structure (b). An outer layer enriched in nitrogen, while the interlayer enriched in carbon.

Strong DLC films stress dependence of the plasma treatments was observed. The stress reduction suggests an increase in the DLC films adherence to metallic substrate. Tribological tests also confirmed these results. The obtained experimental results demonstrated that the preliminary treatment of the metallic surface is fundamental to obtain a high adhesion of the protective coatings.

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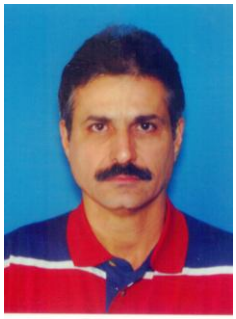

Gil Capote *was born in Havana, Cuba in 1960. He received his BS and MSc in Physics and Mathematics from Saint Petersburg University, Russia, in 1985 under the direction of Professor Evgeny Petrovich Grigoriev, specializing in Nuclear Physics. He obtained his PhD in Physics from the Pontificate Catholic University of Rio de Janeiro (PUC-Rio), Brazil, in 2003 with the guidance of the Professor Fernando Lazaro Freire Jr, studying thin film deposition of Diamond-like Carbon (DLC).*

He worked as a Researcher for several years at the Center of Applied Studies for Nuclear Development (CEADEN) in Havana, Cuba. He worked as a postdoctoral fellow at the National Institute of Space Research (INPE), in Brazil, with Professor Vladimir J. Trava-Airoldi. His current research interests include nanostructured materials, growth and analysis of thin DLC films, interfaces studies and surface modification. He is currently working as a Professor at National University of Colombia.

Prof. Capote was member of the Cuban Society of Physics. Currently, he is member of the Brazilian Society of Physics, the Brazilian Society of Vacuum Applications, the Colombian Society of Physics, and the Colombian Society of Engineering Physics. He has been published scientific papers in many specialized scientific magazine, principally, in Thin Solid Films, Diamond and Related Material, and Surface and Coatings Technology, among others.

Plasma Surface Treatment of Carbon-Based Coatings for Superlubricity and Ultra-Low Wear

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Carbon-based materials and coatings, such as diamondlike carbon (DLC) have been shown to possess exceptional optical, electronics, and surface mechanical and tribological properties that are of great importance for a variety of advanced engineering applications [1]. In recent years, a variety of DLC coatings (hydrogen-free, highly hydrogenated, nano-alloyed, etc.) have been developed and applied to a variety of machine components and magnetic hard disks to combat friction and wear as well as for the prevention of corrosion and other types of environmental degradations in aggressive media [2]. In this study, we introduce a simple plasma treatment method that can make such carbon films superlubricious. Specifically, if we apply a bias voltage of about -400 V to about -600 V to hydrogen gas in a plasma enhanced chemical vapor deposition (PECVD) chamber, we instantly generate a high-intensity hydrogen gas-discharge plasma. If we then subject the DLC coatings to this plasma, we achieve a surface plasma-modified DLC providing very low friction and wear properties. The type of gases to be used in the PECVD chamber may include H_2, NH_3, or deuterium. We found that subjecting the carbon films to these gas-discharge plasmas from about 1 second to about 30 seconds is enough to chemically alter their top surface layers and thus bring their friction coefficients from about 0.8 to less than 0.01 as shown in Fig. 1.

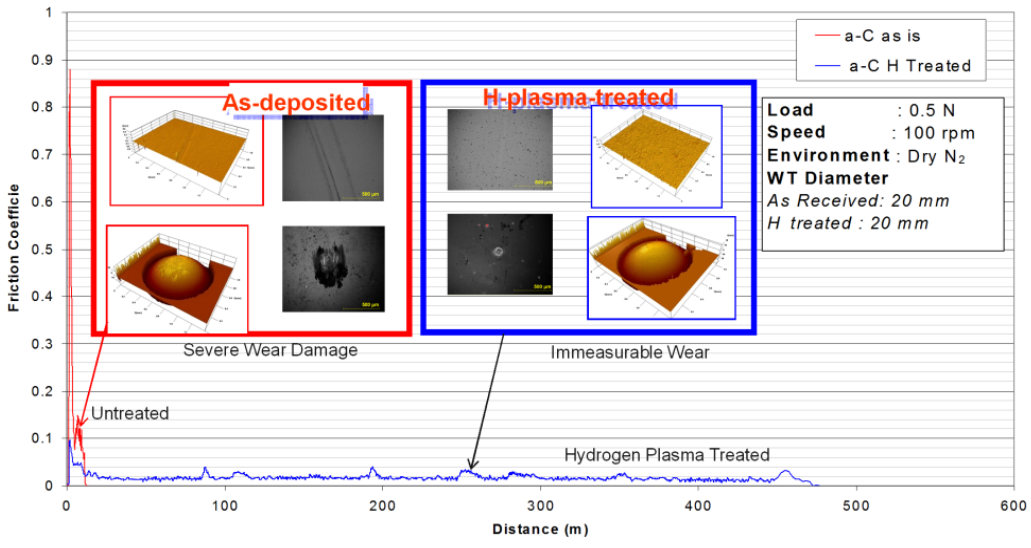

Fig.1. Effect of hydrogen-plasma treatment on friction and wear of a hydrogen free (a-C) DLC film. Without hydrogen treatment, film gives very high friction coefficient (as high as 0.87) and then fails quickly after about 10 m of sliding distance as shown in the inset figure called "as deposited". However, after hydrogen plasma treatment, the friction coefficient comes down quickly to 0.005 level and the sliding surfaces suffer very little or no wear as obvious from inset photos called "H-plasma Treated"

Furthermore, the wear of plasma treated carbon-based DLC films becomes immeasurable after the hydrogen gas plasma treatments. In this presentation, we will elaborate on the fundamental surface physical, chemical, and tribological mechanisms that were primarily responsible for such dramatic reductions in friction and wear of these DLC films after a short-duration plasma surface treatment in PECVD system. We will also elucidate the surface chemistry of plasma treated DLC films using time-of-flight secondary ion mass spectrometer and other relevant surface sensitive techniques and propose a mechanistic model that can explain the very critical role of surface plasma treatment in superlubricious nature of carbon-based materials and coatings.

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Improved Corrosion Resistance of Multilayer DLC/AlN/Si Structures Exposed to Non-Thermalized Plasmas

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The aim of this work is to compare two materials – DLC (diamond-like-carbon) and AlN and the possibility of dry, non-reactive plasma etching. The investigated materials are quite different – the DLC is a conductive amorphous material and as containing carbon is characterized with low sputtering yield. As far as the DLC is a mixture of hybridized sp2, sp3 and sp1 bonding the resulting film structure depends strongly from the deposition conditions. The AlN films [1] exhibit highly oriented crystalline structure similar to those characteristic for mono-crystals. It is a hard material with typical nano-hardness values exceeding 16 GPa, whereas DLC hardness varies between 9 and 13 GPa. Another important feature of the AlN thin film elaborated in the Plasma Group of the Physics department of ITA is the possibility to govern the crystal orientation which makes this material unique for a specific use. Its compound nature reveals some interesting and unexpected results concerning its response to the ion energetic bombardment or so called dry corrosion. It is a highly dielectric material which fact was not supposed to influence considerably its sputtering, but as will be discussed later this detail is also very important. The preferential sputtering characteristic for the majority of compounds is a decisive factor explaining the material corrosion behavior.

Diamond-Like Carbon (DLC) films exhibit particular physical-chemical properties that make them promising materials for the micro and nano electronics industries [2]. Etching processes are needed to make the applications of this material reliable [3]. Reactive ion etching (RIE) reactors are usually used for this purpose [4, 5], but sputtering of the electrode material can occur, consequently leading to the undesirable production of micro-masking on the film. Additionally, sometimes undesirable needle-like structures are formed in the etched surface. The use of a low pressure plasma jet has been shown to be an alternative for these problems [6].

After thorough study of the nature of the etching mechanisms, we found that the crystalline AlN thin films do not exhibit smooth and consistent etching typical for most thin films. They show incredible resistance against the concentrated plasma not only due to their high value of the hardness, but mostly because of charging of the outmost surface, acting like a powerful capacitor repealing the accelerated species when they reach a critical distance λ (discussed below in the text). Despite this high corrosion resistance the highly-crystalline

AlN films could be subject of breakthrough in points of defect on the surface which act as a “nano-opening” causing later micro-avalanche mechanism of layer destruction. Surprisingly to that we discovered that adding a DLC layer with one nominal depth improves considerably the corrosion qualities of the system. The complex mechanism of protection is described in this work.

Besides the home-made HCS we have been used various method of film characterization giving us better understanding of the process taking place in the non-equilibrium plasma media. The most important technique used is the Alpha-step profilometry, SEM, AFM, EDX and RBS techniques. Moreover the etching parameters have been studied in case when the incoming charged particles has different incident angle.

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Increasing the Surface Energy of TiO_2 Thin Films with Incorporation of Nitrogen Atoms in the Film Lattice

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Titanium dioxide (TiO_2) thin films have been widely investigated since the mid-last century for several technological applications [1]-[3]. In the most of them, modifications on TiO_2 surface plays a fundamental role to attain the best results. The increase of the surface energy is one of the main factors necessary to obtain the better performance as, for example, for hydrogen production [1] or osseointegration in dental implants [3]. This improvement may be achieved by several methods. The most traditional ways is doping TiO_2 with metal or non-metal atoms, production of oxygen vacancies in the TiO_2 lattice or just by exposing the film surface to UV light. This latter method is known as the photoinduced hydrophilicity effect [1]. In this paper, in particular, we conducted studies about the effect of nitrogen doping on the surface energy of TiO_2 thin films deposited by reactive sputtering.

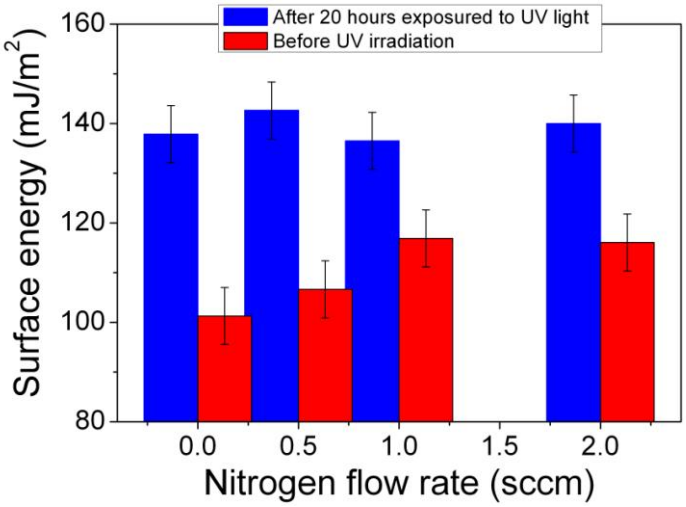

Fig.1. Surface energy as function of the nitrogen flow rate for films analyzed before and after exposition to UV irradiation.

Experimental setup

Undoped and nitrogen-doped TiO_2 thin films were deposited on p-Si (100) substrates from sputtering of a metallic Ti target (99.6%) immersed in a reactive gas mixture of nitrogen, oxygen and argon. Films were deposited at different nitrogen flow rates (0, 0.5, 1.0 and 2.0 sccm). Other experimental parameters like deposition time, DC power supply, target-to-substrate distance, oxygen flow rate, argon flow rate and working pressure were fixed at 30 minutes, 150 W, 15 mm, 3.3 sccm, 19.7 sccm and 0.7 Pa, respectively. The substrate was kept in floating potential during all depositions and its temperature was kept below 100 ^{o}C. The working pressure was set at constant value since the modifications of the nitrogen flow rate does not modify significantly the total pressure. The wettability was studied through measurement of the contact angle between the de-ionized

water drop and the solid film surface. The drop volume was fixed at 0.9 µl. The photoinduced hydrophilicity effect was evaluated through exposition of the films into UV irradiation during 20 hours using a mercury lamp (λ = 253.7 nm, electrical power = 4W). Contact angle measurements were done before and after UV exposition.

The surface energy of the films was calculated from the classical Young-Dupre equation:

$$E_{SL} = \gamma(1+\cos\theta) \quad (1)$$

with E_{SL} the adhesion energy per unit area in the solid-liquid interface, γ the surface energy density of water (72 mJ/m^2) and θ the contact angle between the de-ionized water and the solid film surface.

Results and Discussions

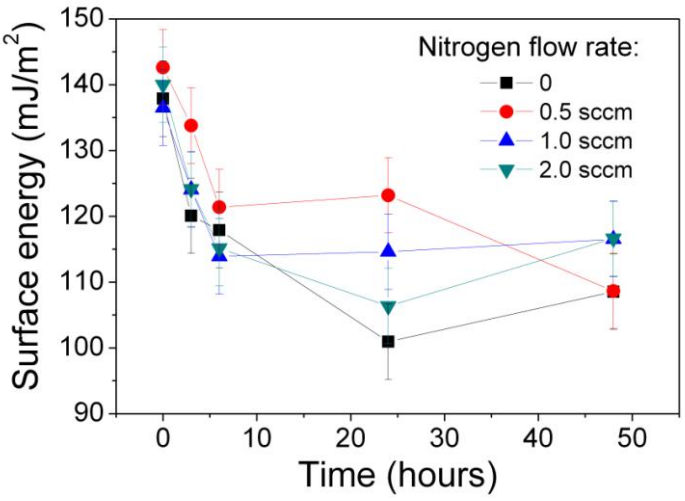

Fig.2. Time dependence of the surface energy during the back-reaction

The effect of nitrogen doping and UV irradiation on the surface energy of the films is shown in Fig. 1. Before exposition to UV light, the surface energy was increased after nitrogen incorporation. This effect may be caused by several parallel effects. Between them, we get the chemical states inserted by nitrogen atoms, generation of oxygen vacancies caused by nitrogen incorporation and increase of the surface roughness caused by modifications in the diffusion coefficient. After exposition to UV light, films become hydrophilic and the surface energy increases abruptly. The time-stability of this parameter, after achievement of the photoinduced hydrophilicity, is depicted in Fig. 2. Despite it is shown that the surface energy was increased after irradiation with UV light, it rapidly decreases in the first hours after removing the irradiation. The incidence of UV light on TiO_2 surface increases the production of electron-hole pairs in the electronic structure of this material. Each hole created in the film bulk diffuses, in a picosecond scale, to the film surface and promotes the dissociative adsorption of water. As consequence, this effect increases the presence of hydroxyl radicals on film surface and gives the hydrophilic behavior to the TiO_2 film [1]. After removing the UV light, the electron-hole recombination increases, thereby, decreasing the presence of OH radicals and the hydrophilic behavior. A brief explanation for this issue is conducted in a previous publication [4].

Conclusions

In this paper the effect of nitrogen doping in the surface energy of TiO_2 thin films was investigated. Results pointed out that the incorporation of nitrogen atoms, as well as, the incidence of UV irradiation increases the surface energy of the films.

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Plasma Electrolytic Oxidation as a Surface Treatment for Valve Materials

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Introduction

Plasma Electrolytic Oxidation (PEO) also known as Microarc Oxidation (MAO) can be viewed as an electrochemical process utilizing high voltage discharges in special conductive solutions (Fig. 1). The primary function of the process is to form adherent, hard, dense oxide layers on valve material such as aluminum, titanium and magnesium. Generally the hardness and density of properly formed layers is better than what can be achieved from plasma spraying or anodization. The process was initially investigated in the 1950's by Russian scientists. More recently the process has been investigated in greater detail by various researchers [1]-[3]. Commercial results have been varied and this can be attributed the lack of scientific knowledge of the process when developing applications. Although much work has been conducted concerning the microstructure of coating [4]-[6], little has been reported on the electrical properties of these coating. This paper reports the dielectric breakdown voltage of coatings formed on 6061 aluminum, an important alloy used in construction of semiconductor chambers where protection against arcing is important.

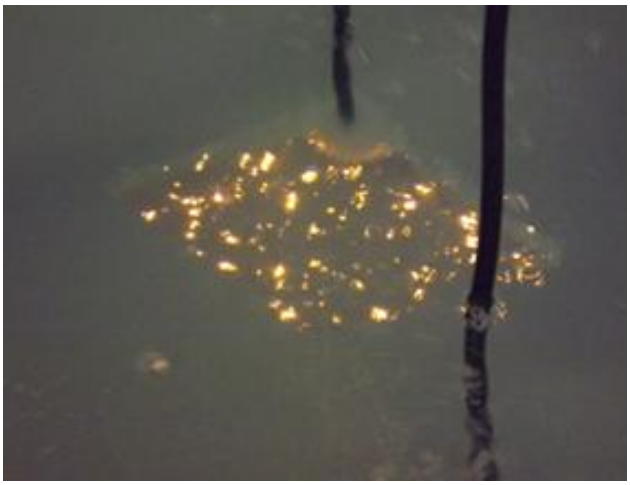

Fig.1. Plasma discharge phenomena in PEO

PEO is carried out in mildly alkaline electrolytes, for aluminum alloys the preferred solution consists of mixtures of potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3). A high voltage power supply capable of supplying over 200 V at current densities of 0.1-0.3 A/cm^2 is required. The power supply can be either AC or DC. Studies have found that pulse shaping can have a very important effect on coating quality and growth [7]. Substrate can be biased to a counter electrode or in the case of AC the potential can be applied between two like sized parts. The high temperature generated in this process requires the solution to be cooled.

Coating growth mechanism is based on formation of discharge channels caused by local dielectric breakdown of the oxide layer. The extreme temperatures melt and expel the valve material out of the channel where oxidation occurs in contact with the electrolyte. The volcano like mechanism leads to a distinct pancake formation on the coating surface (Fig. 2).

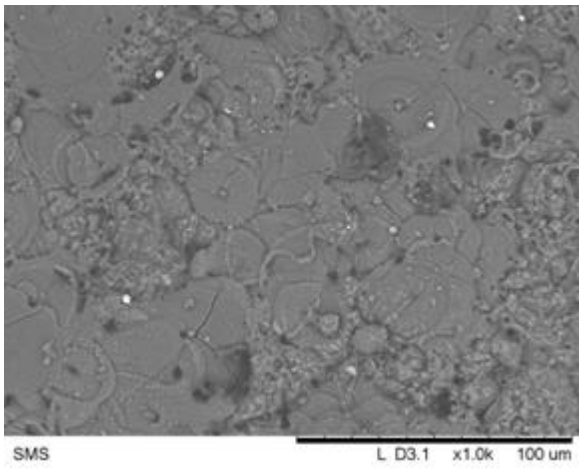

Fig.2. Pancake formation due to metal expulsion from discharge channels

Experimental

A self-constructed AC power supply with a capacity of 480 V and 30 A was used in this study. 6061 aluminum pins measuring 5 mm in diameter and 12 mm in length were used as substrate. The bath chemistry and incoming power was regulated using resistors. Coated specimen was examined under scanning electron microscopy after measuring breakdown voltage using an insulation puncture tester.

Results and discussion

A set of experiment were conducted to investigate the electrical responses during the coating cycle. It was found that upon power initiation the voltage rose gradually to about 200 V at which multiple micro-discharges started to occur at the specimen surface. These were whitish in color, at about 320 V the discharge frequency lessened and the size of the discharges increased (macro-discharge). The color of the discharge changed to yellow as shown in Fig. 1. It was postulated that the coating growth commences at 200 V and grows rapidly to 320 V where coating growth slows and eventually stops at 480 V.

The bath chemistry was varied by keeping the KOH concentration constant at 1.5 g/l while the sodium silicate concentration was changed from 0, 4, 8 and 16 g/l. The power input was changed by increasing the resistance value once stability was achieved at each resistance level. The coating sequence was terminated once the voltage reached 480. In the case of the 16 g/l samples initial attempts lead to uncontrolled growth and non-adherent coatings. The current density had to be lowered considerably by use of ballast plates to control the coating growth rate. It was noticed that the voltage stayed with 300-350 V the majority of time.

Table 1. Coating Thickness and Breakdown Voltage versus Sodium Silicate Concentration

Concentration Na_2SiO_3 g/l	0	4	8	16
Thickness (µm)	35	60	100	120
BDV (V)	0.007	0.025	0.013	0

Table 1 summarizes the thickness and dielectric breakdown voltage (BDV) data from the experiments.

It can be inferred that slowing down the growth rate leads to better dielectric properties then dramatically increasing the thickness via addition of sodium silicate. This can be understood from the observance that keeping that coating growth in the 200-320V range leads to micro-arcing and the formation of very small discharge channels in the coating whereas prolonged exposure to higher voltages leads to macro-discharges and the formation of larger discharge channels. During breakdown voltage testing as the voltage is increased it is easier to penetrate through the large pores to cause electrical breakdown.

Summary

A novel method of forming dielectric coatings on aluminum has been developed. The PEO system has to be closely controlled to optimize the current density and thus the coating growth rate in order to achieve high dielectric strengths. A slow growth rate in the micro-arc region allows formation of smaller defects and denser coatings.

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Wear Behavior and Chemical Processes that Control the Lifetime of Electromagnetic Railguns

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The electromagnetic railgun is a practical alternative to conventional propellant-driven guns. Two types of railguns have been studied, and both operate on the same electromagnetic principle: an armature is propelled by the Lorentz force. The difference is that in the former, the current passes from conductive solid armature to conductive rail; in the latter, the current forms a plasma armature. This talk will describe railgun developments with conductive armatures and present lubrication schemes and analytical studies carried out at the US Naval Research Lab. One railgun delivers its projectile at subsonic (140 m/s); the other at supersonic (1-2.5 km/s) speeds. Two objectives in this basic research study were to identify armature/rail wear behavior and observe dissipation processes in real time. Two high-speed techniques were used to observe armature/rail interactions in the bore and beyond: High-speed video (Phantom camera up to 100,000 frames per second) and short-interval UV/VIS/IR spectroscopy (Ocean Optics at 1 ms per spectrum).

The low speed railgun [1] is being developed as a decoy launcher, intended to launch decoy chaff without the flash accompanying propellant launches. Armature contacts were the first problem encountered. Al contacts on the projectile burned out rapidly, whereas Cu contacts destroyed the rails. This talk reports on a rulon-lubrication scheme that resulted in long-lived rails and armatures [2]–[4].

The high speed railgun is being developed as a long-range weapon, capable of sending projectiles hundreds of km [5]. Al armatures fit two important requirements: light weight and high electrical conductivity. However, at the currents needed for practical projectiles (> 1 MA), the lifetime of the gun is limited by damaged to rails and insulators [6]. The talk presents high speed video and spectroscopy data that address chemical and other energetic processes that occur during and after armature transit down the bore (5 ms) [7].

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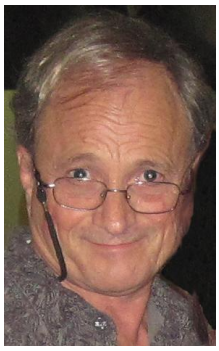

Irwin L. Singer *received a B.S. degree in physics from the Case Institute of Technology (currently Case-Western Reserve), Cleveland, OH, in 1964, and M.S. and Ph.D. degrees in physics (superconductive tunneling) from Indiana University, Bloomington, in 1968 and 1976, respectively. He was a Postdoctoral Fellow in the Surface Analysis Section of the Naval Research Laboratory (NRL), Washington, DC the following year, then joined the Tribology Section in 1978. He was appointed as Tribology Section Leader in 1983. In 2008, he stepped down from being a Section Head to focus on research full time. In September, 2011, he retired and now does consulting with SingerTriboscience, in Alexandria VA USA. During his tenure at NRL, he has been a Visiting Scientist at the following institutions: Instituto de Fisica, UNAM, Mexico City, Mexico (1981–1982); Cambridge University, Cambridge, U.K. (1985–1986); and Ecole Centrale de Lyon, Ecully, France (1992–1993). He has over 200 publications and 3 patents, and has served on the editorial board of three journals. He is also the Coeditor of the book “Fundamentals of Friction: Macroscopic and Microscopic Processes” (Dordrecht: Kluwer, 1992). His specialty has been interfacial contributions to friction, wear, and adhesion, but has worked extensively on new approaches in surface modification and surface analysis. He has made contributions in the fields of solid lubrication, wear-resistant surface treatments, structure/property relationships in ion-beam-modified metals and ceramics, friction processes at the atomic scale, third-body effects in sliding contacts, debonding from elastomers, and, most recently, high-speed sliding electrical contacts. Dr. Singer is a Fellow of the American Vacuum Society. In August 20120, he was honored by NRL with the Sigma Xi Award for Applied Science, and in August 2012, the American Chemical Society held a symposium honoring his 35 year career in tribology.*

Macroscopic Tribocharge Patterns Formed by Polymer Ion Self-Arraying on Insulating Polymer Surfaces

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Abstract

Tribocharged polymers display macroscopic positive and negative domains, verifying the fractal geometry of electrostatic mosaics previously detected by electric probe microscopy. Charge on contacting polyethylene (PE) and polytetrafluoroethylene (PTFE) follows the triboelectric series and it is the arithmetic sum of patterned positive and negative charges, as opposed to the widespread assumption of uniform charging. Washing with hexane removes preferentially positive charges from PTFE, while 1,1-difluoroethane and ethanol largely remove both positive and negative charges. A model is presented (for PTFE tribocharging with PE), based on the mechanochemical chain rupture generating a low-temperature microplasma where fluorocarbanions and hydrocarbocations are formed through the consecutive steps: free-radical formation, electron transfer, ion segregation according to Flory-Huggins theory and ion stabilization at the polymer surface due to their amphiphilic properties.

Introduction

The tribochemical formation of macroscopic charge patterns on polymer surfaces and the identification of the charge carriers was recently achieved [1], for the first time. The origin and nature of electrostatic charges in insulators has been a matter of current debate [2], and there is much conflicting evidence in favor of electrons [3], ions [4] or both types of charge-bearing species. The very significance of the triboelectric series has been disputed recently [5]. The present authors previously showed that charge partition takes place at gas-solid interfaces, as well as in liquid-solid interfaces.

Experimental

In this work, polymer tribocharging experiments were done by spinning polymer disks on the surfaces of another polymer, under controlled speed and pressure. Charge patterns on the polymer surfaces were determined using a scanning Kelvin electrode. Species formed at the polymer surfaces were extracted with solvents and identified in situ or in the extracts using infrared and electron energy-loss spectroscopy or pyrolysis. Calculations of the stability of the charged species were done using (U)B3LYP/6-31+G(d,p) computational model in Gaussian09 software.

Results and Discussion

When a polyethylene (PE) disk is spun over a polytetrafluoroethylene (PTFE) surface, macroscopic domains with opposite charge are formed displaying electrostatic potentials in excess of +/- 3 kV, as shown in Fig. 1. The same is observed in other analogous experiments made using various other polymers and glasses. These results confirm the fractal nature of surface charge distribution in insulators that was described in earlier publications from this laboratory. Using an array of microanalytical techniques, positive domains on PTFE are

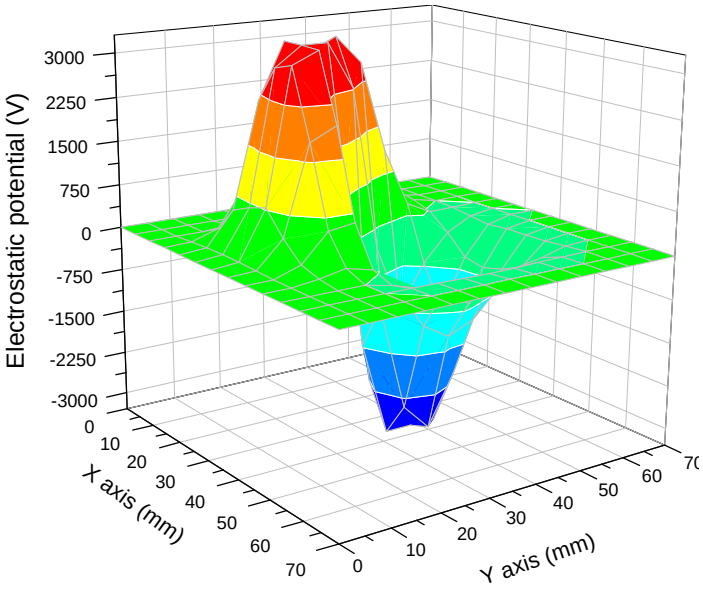

Fig.1. Macroscopic electrostatic pattern formed on PTFE surface by rubbing it with a PE foam disk

identified as PE fragments while the negative ions are PTFE fragments. Fig. 2 shows infrared microspectra of positive and negative domains on PTFE.

Tribocharges are extracted from polymer surfaces by using both nonpolar and polar liquids but showing solvent specificity. Charge formation is thus explained by the following model: polymer chain scission produces mainly homolytic chain scission that is followed by electron transfer driven by electronegativity: electrons from PE free-radicals jump to PTFE radicals producing fluorinated anions and polyethylene-derived cations. Cation and anion chain fragments segregate into charge islands, according to their chemical nature and following Flory-Huggins theory, according to which polymers are immiscible. Ion stability at the polymer surfaces is explained by their tendency to occupy subsurface layers, to minimize surface tension of the solids.

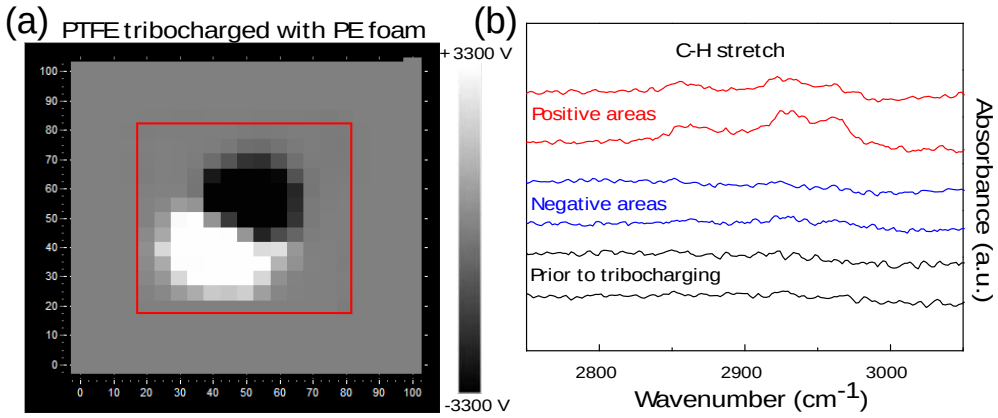

Fig.2. (a) Electrostatic potential map of PTFE tribocharged with PE and (b) infrared microspectra of PTFE positive, negative and neutral surface domains, showing the presence of PE residues on the positive domains

Conclusions

Triboelectricity in polymers consists of macroscopic charge patterns on the contacting surfaces, which is different from the usually assumed one-way charge transfer. Pattern formation is understood following the new mechanism described in Fig. 3, representing low-temperature microplasma formation triggered by mechanochemical polymer chain rupture.

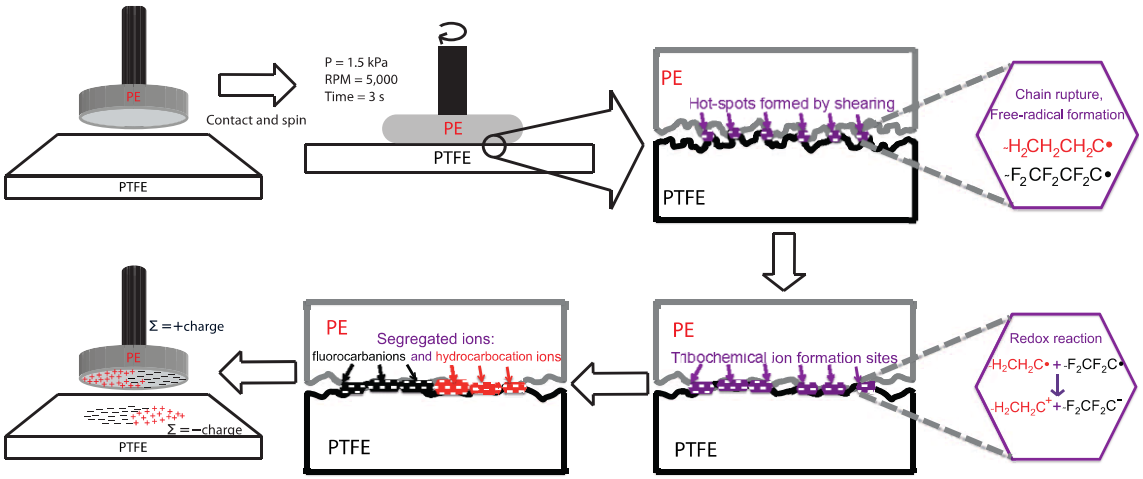

Fig.3. (a) Mechanism for contact triboelectrification of insulating polymers

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Study of the Titanium Surfaces Modified by Plasma Immersion Ion Implantation and Deposition

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Titanium has been widely used as a biomaterial due to its biocompatibility and good mechanical properties. However, the bone-implant integration is still a problem. Frequently, the metallic implant is encapsulated by a fibrous tissue, which blocks the chemical junction of the material to bone. According to this, superficial treatments are performed to improve the interaction of the surface with body fluids in order to increase the growth of living cells. The incorporation of calcium on the surface of this metal by ion implantation has shown good results for bioactivity [1]. However, this is an expensive technique and the treatment of implants with complex geometries is complicated. An alternative is the plasma immersion ion implantation and deposion techinique, PIIID, which is cheaper and allows the uniform treatment of samples with irregular geometries. In this work the deposition of calcium-containing films onto titanium samples has been performed, in a stainless steel chamber, by PIIID in atmospheres of argon and vapor of $1.27x10^{-2}$ mol of $Ca(NO_3)_2.4H_2O$ diluted in 10 ml of isopropyl alcohol in a system fully described elsewhere [2]. The total pressure inside the chamber was kept constant at 5.71 Pa while the partial pressure of the calcium-containing vapor, R_{Ca}, ranged from 50 to 100%.The discharges were generated by the application of radiofrequency power (13.56 MHz, 100 W) to the top electrode while high voltage negative pulses were applied to the lowermost electrode, which also works as sample holder. After PIIID process, the treated titanium substrates were immersed in solution body fluid, SBF, during 14 days at 37^{o}C [3]. Alterations caused by PIIID and the effect of the soaking in SBF were evaluated by electrochemical impedance spectroscopy (EIS). Impedance data were presented as Bode plots, and a comparison was made between the impedance results before and after soaking of the treated samples in SBF. Osteoblastic cells [4] (105 cel/ml) was seeded on the coated titanium by PIIID and controls in osteogenic DMEN and cultured for 2h and 24h to allow cell adhesion and viability, respectively, at 5% CO_2 and 37°C [5]. Cell adhesion and viability tests were carried out by MTT assay [6]. Roughness and surface energy of the films were measured by perfilometry and contact angle data, respectively.

Fig. 1 shows the results of EIS of pristine titanium before and after soaking in SBF. The phase angle near 90 degrees for intermediated and low frequency range is characteristic of a

compact passive oxide layer [7]. After immersion in SBF there were not significant alterations on surface as can be seen by invariance in phase angle and impedance module curves. The samples treated with 90, 95 and 100% of R_{Ca}, showed the higher variations in the surface after PIIID and after soaking these samples in SBF. For these samples were obtained phase angle and impedance module diagrams as shown in Fig. 2. Phase angle curve, before soaking in SBF, exhibited two concavities, indicating two layer film. The high phase angle in intermediate frequencies is due the a compact inner barrier layer, while the drop in phase angle for lower frequencies is due a porous outer layer. Soaking in SBF seemed to contribute to the incorporation of species into the porous of the layer, modifying the phase angle response. This modification is also accompained by a linearization in the impedance module diagram. The alteration in shape of the curve after soaking in SBF indicates that the change caused on surface by plasma promoted interactions of the surface with the SBF. This behaviour was different to the pristine titanium in which there was not change.The Fig. 3 (a) shows the cell viability as a function of the polar components of the surface energy, Ep. For the samples treated in low partial pressure of the calcium-containing vapor, the increase of the Ep is accompained by increase in viability. Due to high surface energy the living cells adsorbed are anchored and then adhered to decrease the interfacial tension solid/liquid. For the sample treated in 95% of R_{Ca}, the high viability is due the higher roughness as can be seen in Fig. 3 (b). The viability increased 100% in this sample compared to pristine titanium (absorbance = 0,3).

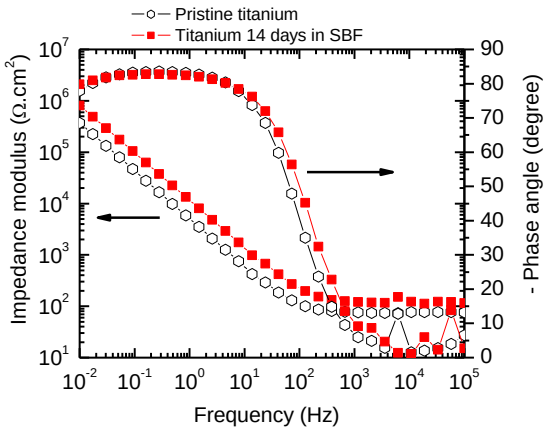

Fig.1. Phase angle and impedance modules of pristine titanium samples before and after soaking in SBF for 14 days

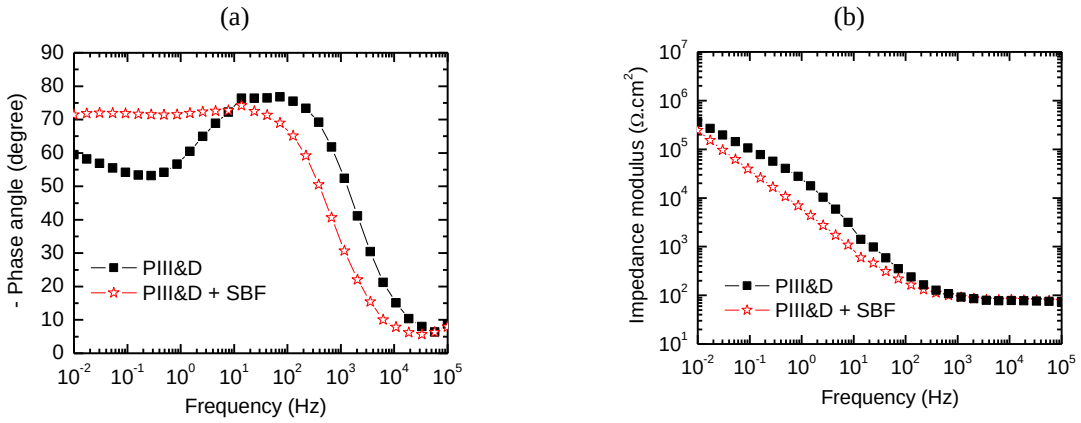

Fig.2. (a) Phase angle and (b) impedance modules of PIIID treated titanium samples before and after soaking in SBF solution

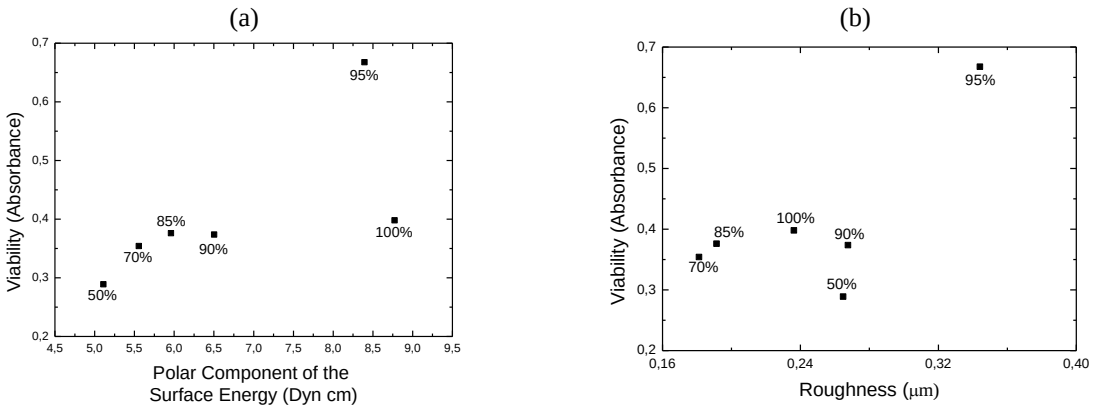

Fig.3. (a) Cell viability as a function of the polar component of the surface energy. (b) Cell Viability as a function of the roughness

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TiO2 Films Deposited by Grid-Assisted Magnetron-Sputtering

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TiO_2 is a semiconductor material that have applications in different areas like heterogeneous photocatalysis, solar cells, electronic and optical properties and self-cleaning surfaces [1]-[3]. In its rutile form, TiO_2 films exhibit a high dielectric constant, a good thermal stability and a high refractive index (2.75 at 550 nm), which make them a good candidate for optical and electronic applications. The anatase TiO_2 phase exhibits chemical properties that allow it to be used in photocatalytic processes, gas detectors and self-cleaning windows [5].

In this paper we studied the reactive deposition of TiO_2 films using a Grid Assisted Magnetron Sputtering system. In this system it is possible deposition with lower pressures and higher proportion of reactive gas before the occurence of the target poisoning [6]-[8].

The hysteresis loop is a characteristic of reactive deposition by sputtering systems. It can be reduced in the Grid Assisted system. It occurs mainly due the chemical adsorption processes on the grid between the target and the substrate, prior to the complete coverage of the target surface (poisoning). This system presents greater plasma stability for TiO_2 reactive deposition. It was observed that is only possible to obtain stoichiometric TiO_2 films when the film deposition is made with target in oxide mode. This occurs with high partial pressures of oxygen in the chamber. The films were characterized by X-ray diffraction (XRD, $\lambda_{Co} = 0.1794$ nm), optical transmittance (UV-Vis spectrometer Jasco Corp. V 570) and Rutherford Backscattering Spectroscopy (RBS). Fig. 1 (a) presents the results of optical transmittance versus wave-length, for samples covered with TiO_2. The films deposited in the oxide mode, exhibit high light transmittance for wavelength between 330 and 2000 nm. Fig. 1 (b) shows the results of RBS spectra and simulated curve of sample covered with TiO_2 in oxide mode target. The ratio O/Ti was 1.95, that is, very closed to the stoichiometric TiO_2 films.

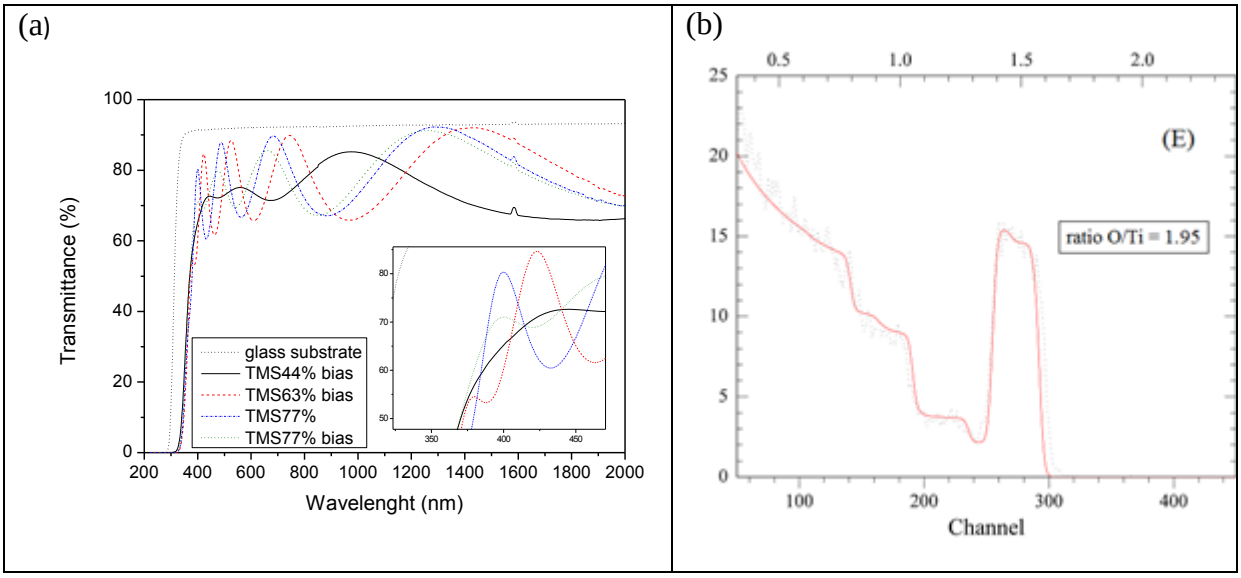

Fig.1. (a) Optical transmittance curves versus wavelength of incident light on samples covered with TiO_2, deposited by Grid Assisted Magnetron Sputtering in oxide mode; (b) RBS spectra and simulated curves that shows the ratio O/Ti = 1.95

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Deposition of Diamond-Like Carbon films by High Power Impulse Magnetron Sputtering - HiPIMS

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Diamond-like carbon (DLC) is a metastable form of amorphous carbon containing a significant fraction of sp^3-hybridized bonds [1]. This quantity of sp^3-hybridized bonds depends on the deposition technique and the forerunner used. In plasma assisted physical vapor deposition (PVD) techniques, the energetic species are predominantly inert gas and target-based ions, and their kinetic energies can be controlled by the use of substrate bias voltage [1], [2]. From PVD techniques magnetron sputtering (MS) is the most used in industrial processes, due to its conceptual simplicity and its ability to deposited uniform films with relatively high rates [2]. However, magnetron sputtering plasmas are characterized by relatively low electron densities (~10^{15} m^{-3}) and low degrees of ionization of both gas and sputtered species [3]. In the case of deposition of amorphous carbon films, it has been shown that using this technique it is very difficult to obtain high sp^3 bond fraction films [4], and the films presents–high values of compressive stress, causing poor adhesion to the substrate, especially on steel, which limits the range of industrial applications [5]. A way to reduce this problem is using a HIPIMS system, where the power is applied to the target in pulses of low duty cycle (<10%) and frequency (<10 kHz) leading to pulse target power densities of several kW cm^{-2}. The HIPIMS system operation mode results ultra-dense plasmas with unique properties, such as a high degree of ionization of the sputtered atoms [6].

In this paper DLC films were deposited on Si substrates by HiPIMS and dcMS (dc magnetron sputtering) at different powers: 100, 300, 500 and 700W. In the case of HiPIMS the duty cycle was 2% and the frequency 250 Hz. Initially, the species of the plasma were studied by optical spectroscopy. Fig. 1 shows the spectra produced by dcMS and HiPIMS at 700W, respectively, and beside each spectrum there is an image obtained from the generated plasma, produced by each power supply. It is noted in these graphs vertical lines that represent the intensity values of ionized species. These spectra shown ArI lines (related with neutral argon) in the wavelength range of 7000 – 9000 Å due 4p → 4s and 5p → 4s transitions. It can be noted that the spectrum for the plasma produced by HiPIMS, promoted an increase in the intensity of lines in the region between 3500-5000 Å, that corresponding to transitions Ar I, Ar II (ionized) and Ar III (double ionized), indicating an increase in the ionization of the discharge.

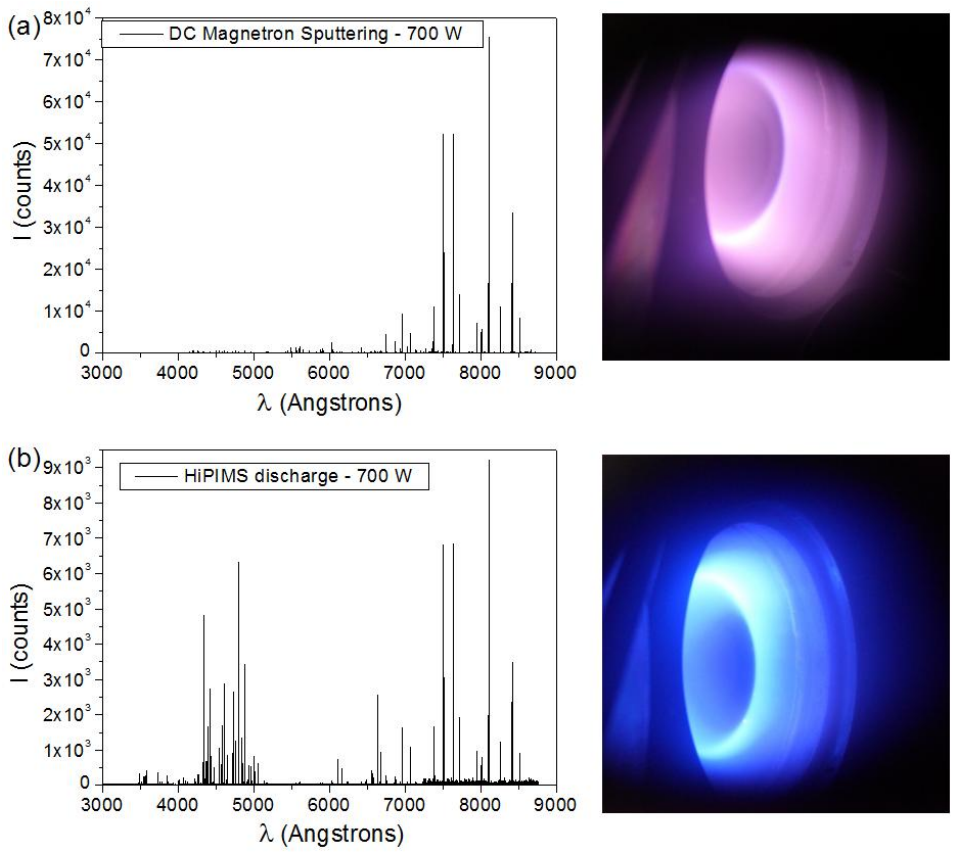

Fig.1. Optical emission spectra of Ar discharges produced by (a) dc magnetron sputtering, and (b) HiPIMS

The studies of the properties of the deposited films, such as structure, adhesion and chemical composition are being carried-out and will be related to the plasma parameters. Studies showed that Ar^+ and C^+ energy distribution functions are higher for HiPIMS, which leads to increased energy transfer to the film [2]. Therefore, it is expected that the increase of the ionization discharge produces a denser film and with greater sp^3-hybridized bonds.

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A Global Model Coupled with Langmuir Adsorption Kinetics Applied for Investigation of Inductively Coupled CF_4 Plasma Etching of Silicon

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Carbon tetrafluoride (CF_4) is a common etchant in the microelectronics industry. It is commonly used to etch silicon-based materials such as Si, SiO_2, SiC, Si_3N_4, etc. The presence of carbon in CF_4 molecule structure allows, depending on the process parameters, to obtain highly anisotropic profiles due to polymerization of the walls of etched structures [1]. Due to the complexity of fluorinated plasma environment during silicon-based material etching, there are few works presenting experimental and/or theoretical studies about the chemistry and main mechanism involved in this dry etch-type process.

In this work, a global model coupled with Langmuir adsorption kinetics has been developed to study the plasma chemistry of reactants and products during inductively couple CF_4 plasma etching of silicon (Si) as a function of process parameters such as discharge power and pressure. A complete set of gas phase reactions with respective reaction rates was mounted for CF_4 plasma considering the last database presented in literature [2, 3]. Moreover, through the Langmuir adsorption kinetics model the products of interaction plasma - Si substrate surface (for example, SiF_x species, x = 0-4) are calculated and considered as a second gas source in the balance particle formulation of global model. Besides, the determination of plasma parameters such as temperature and density of electrons, with the knowledge of the concentration of SiF_x species is possible to determine the vertical and horizontal etching rates, and consequently, the anisotropy of the process.

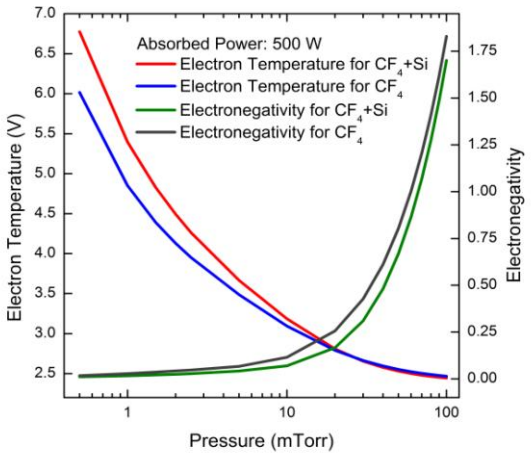

Fig.1. Electron Temperature and plasma electronegativity as a function of gas pressure for 500 W absorbed power

Fig. 1 shows the electron temperature and electronegativity as a function of gas pressure for conditions with and without silicon wafer. It known that the gas pressure into the vacuum chamber has a strong influence on the process anisotropy. Low pressures make anisotropy better because reduce collision number between neutral molecules and ions on the sheath. However, the electron temperature increases in low pressure cases with insertion of Si wafer (Fig.1). This fact can be explained by high dissociation of CF_4 gas and addition of plasma-silicon surface species such as SiF_x that increases the collisional energy for generation of electron-ion pair and, consequently, the electron temperature. Fig. 1 also illustrates that the plasma

electronegativity decreases with the inclusion of SiF_x species in plasma environment, which results in the reduction of the fluorine species (such as fluorine negative ion).

Fig. 2 illustrates the last discussion with the plot of the neutral density of CF_4, F, SiF_4 and electrons as a function of time.

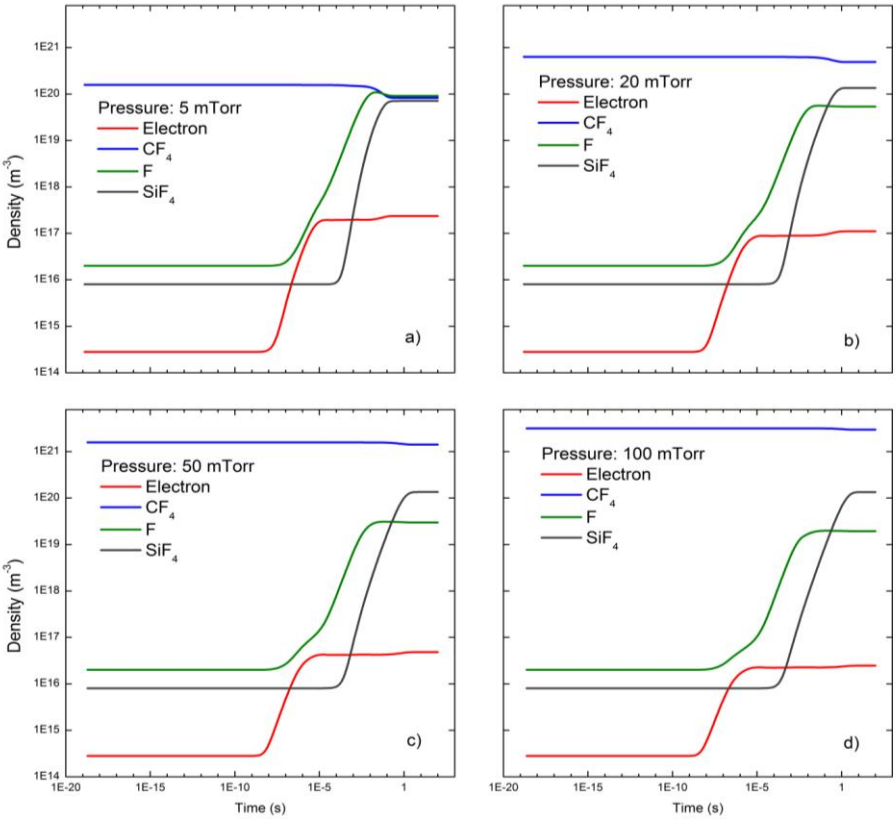

Fig.2. Particle density of electron, CF_4, F and SiF_4 on a) 5 mTorr, b) 20 mTorr, c) 50 mTorr and d) 100 mTorr pressure

Vertical etch rate gets a high increase on very low pressures range whereas it is null for another values out of this range pressure (Fig. 3). Improvement on model is being done to include horizontal etch rate.

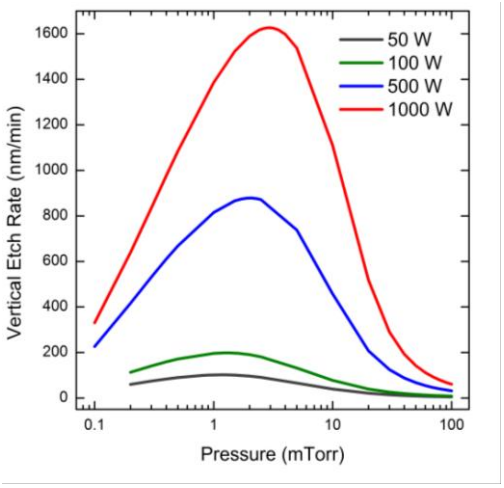

Fig.3. Vertical etch rate as function of a gas pressure

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Temperature Studies on DLC Film Growth for Space Applications

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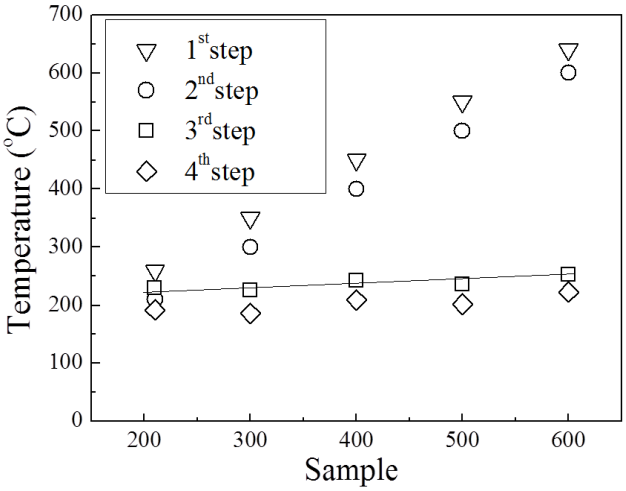

Fig.1. Variation on heating temperature during film growth steps

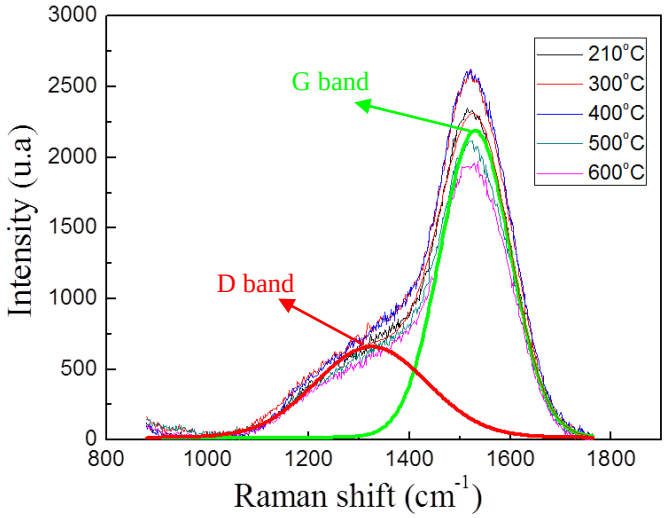

Fig.2. Raman spectra of the films

DLC (Diamond-Like Carbon) films are known to have various properties such as chemical stability, low friction coefficient and high hardness. The film properties qualify them for application on various sectors, such as chemical, automotive and space [1]-[2]. In this study DLC films were grown on Ti6Al4V substrates by Plasma Enhanced Chemical Vapor Deposition (PECVD) [3].

The deposition procedures were done in four steps. In the 1st step the substrates were heated in argon plasma for adhesion improvement. In the 2nd step, was deposited a silicon interlayer. These steps were carried out in different temperatures (210°C, 300°C, 400°C, 500°C e 600°C). In the 3rdstep, hexane was introduced into the chamber in order to produce a mixed layer of carbon and silicon. Finally, in the 4th step, DLC films were deposited at temperature of about 200 °C. Fig. 1 shows the temperature for the substrate at each step.

The films were characterized by optical profilometer, Raman spectroscopy and scanning electron microscopy (SEM), in order to measure the thickness, structure and grain size of the films, respectively. Fig. 2 shows Raman

spectra of the samples deposited for different temperatures in the 1st and 2nd steps. These results show that the deposited films are high quality DLC evidenced by D band centered in 1332 cm^{-1} and G band centered in 1580 cm^{-1}. The I_D/I_G ratio for sample deposited at 210 ^oC was less graphitic with magnitude of 0,47 that 11% less that the sample 600 [4].

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Afterglow Microwave Plasma Surface Treatment of EPDM Rubber for Aerospace Application

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In the aerospace industry, the development and manufacture of missiles and rockets solid propellants, require the use of highly charged flexible thermal protection with improved thermomechanical properties, ablative and adhesive to replace the traditionally used butadiene acrylonitrile copolymer (NBR) or polyurethane (PU), shown in Fig. 1. This thermal protection can be mainly used in ignition systems, control, sealing and lining the chambers propellants, which are usually designed in metallic materials or composites.

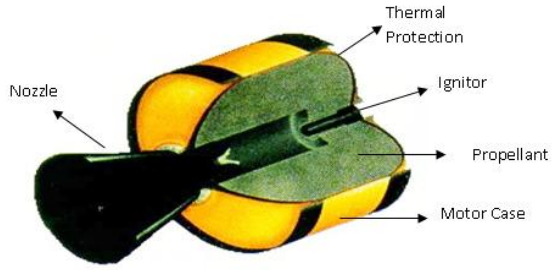

Fig.1. Rocket-motor structural picture

The selection of the composition and manufacturing of rubber used as protective thermal lining inside the driver chamber must meet several requirements to mechanical, thermal, physico-chemical and adhesion during storage and combustion of solid propellant. Among these requirements, one that deserves special attention is the interface compatibility between the rubber and the propellant.

This work was chosen ethylene propylene diene monomer (EPDM) as the base polymer of the rubber compound is mainly the ability to absorb larger amount of charge than the other polymers, coupled with its lesser density, less toxic product of combustion, less aggressive to the environment and manufactured in Brazil, however, difficult compliance with the solid propellant-based PU [1].

In order to improve the compatibility between the vulcanized rubber and the solid propellant used today makes it necessary to promote the activation of the surface of the rubber. Currently, the technique used to promote the activation of rubber to promote better adhesion is mechanical abrasion and chemical attack later, however, this technique is ecologically incorrect, because it use halogenated and isocyanate solutions. Advances have been made in recent years to render polymers and rubbers surfaces with desired chemical and morphological properties with negligible changes in the polymer bulk properties [2].

The plasma treatment is a process more versatile and faster, of great importance in the industrial modification of polymer surfaces, since it can generate active species with different simple replacement of gas type, can change surface energy by introduction of chemical

groups [3]-[5]. Furthermore, the plasma treatment can remove surface impurities and increasing its roughness, contributing to increase compliance with the solid propellant. The plasma assisted process is extremely complex, making it difficult in some cases the elucidation of the mechanisms that involve interactions between the plasma and the surface of the rubber. The identification of these surface changes can be carried out by various characterization techniques, including Fourier Transform Infrared Spectroscopy (FTIR), X-ray Photoelectron Spectroscopy (XPS), Atomic Force Microscopy (AFM), Goniometry and Adhesion Test.

This work presents the results of EPDM rubber surface properties treated in afterglow microwave plasma. Fig.1. presents a schematic of the plasma system.

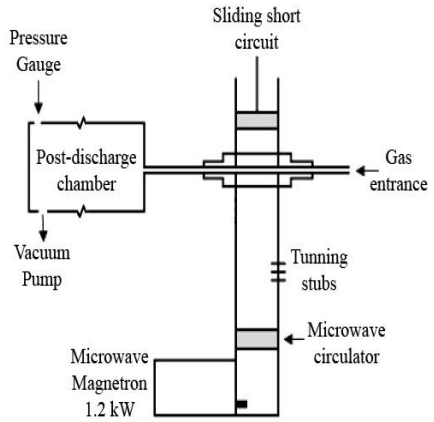

Fig.2. Schematic of afterglow microwave plasma system reactor setup

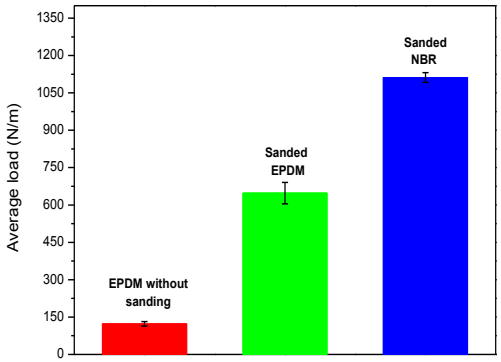

Fig.3. Rupture strength of NBR and EPDM with and without sanding, determined by Peel Test

Initially, was compared the adhesion properties of NBR and EPDM rubbers prepared by the process currently used in the Brazilian Space Program, that is, mechanical grinding followed by solvent cleaning and application of a layer of polyurethane liner. The adhesion properties were evaluated by Peel Test (peeling "T"). The rupture strength is shown in Fig. 3 and confirm that the EPDM rubber has adhesive properties significantly below NBR (less than 50%), which stresses the need to use a surface treatment more efficient.

The plasma treatments were carried out varying the following parameters: treatment time [s], distance of the sample relative to the discharge [mm], plasma power [W], gas mixture and gas flow [sccm].

The EPDM surface energies were obtained by measurements of surface contact angle. The contact angle of water for the untreated EPDM rubber is 111° (surface energy of 24 mN/m). After treatment, the contact angle decreased to below the detection limit (20°) of the goniometer (surface energy 77 mN/m). At this condition we say that the rubber surface has a super hydrophilic surface.

This increase in the surface energy was obtained for different treatment gases (N2, O2, Ar, and there mixture) at different plasma parameters. Fig. 4 present plots showing the oxygen plasma conditions for which the rubber surface possess super hydrophilic properties.

The increase in the surface energy values obtained after different plasma treatments strongly indicate that the adhesion properties of EPDM rubber must have also improved. However, to confirm this, adhesive tests were performed for EPDM rubber treated on

different plasma conditions and the results are summarized on Table 1. The higher surface strength was obtained for EPDM rubber surface treated in $Ar+O_2+H_2$ plasma represents an improvement of about 30% in adhesion compared with the untreated EPDM rubber surface.

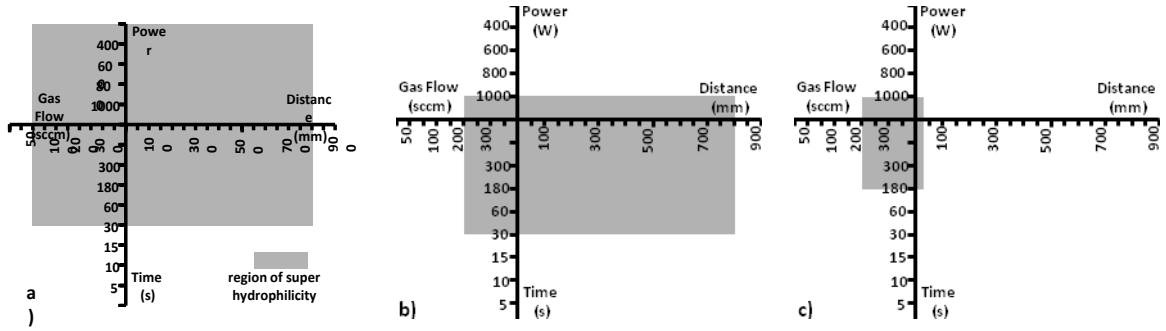

Fig.4. Diagram showing the O_2 plasma treatment parameters for a) 23 mTorr, b) 2.3 Torr and c) 23 Torr, that the EPDM rubber surface is super hydrophilic

This study showed that the afterglow microwave plasma system mounted in Laboratory of Plasmas and Processes - ITA is very effective for the surface treatment of the EPDM rubber.

Table 1. Tensile stress test

Plasma treatment	Maximum load (N)	Standard deviation (N)
Untreated	556	32
Ar	619	69
$Ar+N_2+H_2$	693	42
$Ar+O_2+H_2$	710	86
H_2	598	13
N_2	669	12
O_2	655	35

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His main research interests are concentrated in the material sciences and applied plasma physics, mainly in surface and coatings plasmas material processes.

Combined Cycle Gas Turbine Power Plant with Integrated Plasma Coal Gasification

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Coal as a feedstock for power generation becomes more and more attractive in case of its preliminary conversion into a gaseous fuel named synthesis gas (SG). In this case a combined cycle power plant with integrated coal gasification (IGCC) promises higher efficiency in comparison with conventional wide spread coal-fired power plants based on a steam cycle.

As a further development of the IGCC, one of the authors has offered so named Integrated Plasma Gasification Combined Cycle (IPGCC) [1] which investigation results is a subject of current presentation.

The technological scheme in Fig. 1 has been developed for a high-ash content coal conversion into the SG with further power generation. It considers three methods of SG production with plasma initiation depending on oxidant, namely: (1) air gasification, (2) oxygen gasification, and (3) water steam + oxygen gasification.

To calculate efficiency of the suggested small scale power plant a significant amount of the process parameters have been selected, defined, and modeled. Three different gas turbine engines (GTE) developed by the Gas Turbine Research & Production Complex Zorya-Mashproekt, Ukraine were selected [2]. The GTEs parameters are represented in the Table 1. Coal from the Maikubensk (Kazakhstan) coal reserve with ash content of 24% was considered as a feedstock.

The reason of three gasification methods selection is in possibility to investigate the effect of different caloric value of the SG utilization on the power plant efficiency. To determine optimal coal to oxidant ratio for the plasma gasification processes and balance compositions of the thermo-dynamic systems for all above-mentioned technologies, which allow obtain SG of the maximum heat value, a computer code TERRA was used [3].

Table 2 and Fig. 2, show, as an example, the balances of the IPGCC power consumption for the own needs for a scenario of the high-ash content coal conversion from Kazakhstan into SG with further power production for export, as well as its efficiency in case of the UGT3200 application as a gas turbine.

Conclusions

1. The technological scheme of the IPGCC power plant, including high-efficient heat recovery, multi-staged plasma gasification, and the most advanced gas turbines has been developed and investigated for a high ash content coal as a feedstock.

2. Study of the power plant performance, definition of the basic process parameters as well as specific energy consumption have been held for three SG production technologies: air, oxygen, and steam + oxygen gasification with further feeding of three types of gas turbines with different efficiency.

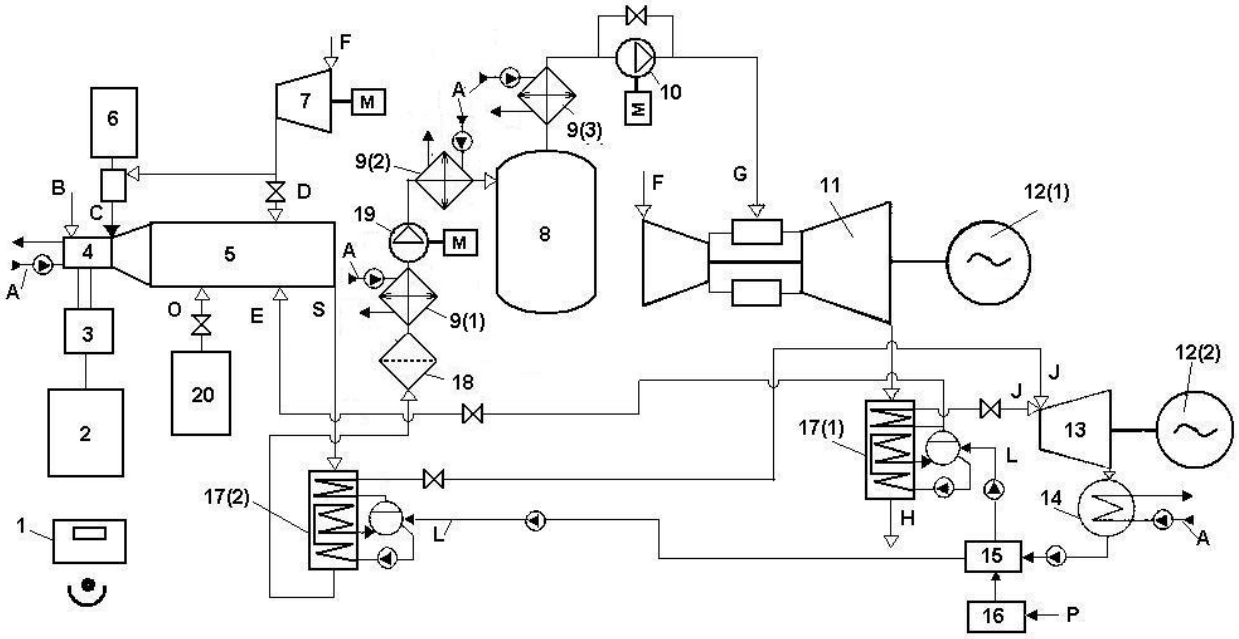


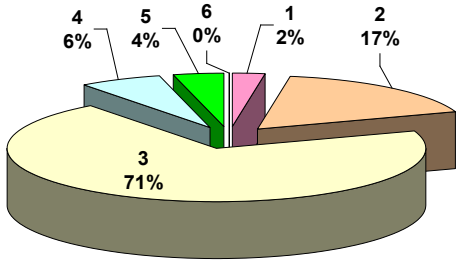
Fig.1. General scheme of a combined cycle power plant with integrated plasma coal gasification. Units: 1 – control system; 2 – plate power module of the RF power source; 3 – RF module; 4 – RF plasma torch; 5 – multi-stage coal gasifier; 6 – coal feeder; 7 – air compressor for coal transportation; 8 – synthesis gas storage tank; 9(1), 9(2), 9(3) – synthesis gas cooler; 10 – fuel synthesis gas compressor; 11 – gas turbine engine; 12 (1,2) – power generators; 13 – steam turbine; 14 – steam condenser; 15 – hot well; 16 – water treatment system; 17 (1,2) – utilization steam generators (USG); 18 – synthesis gas treatment module; 19 – synthesis gas compressor; 20 – oxygen production module. Working mediums: A – cooling water, B – plasma gas; C – coal dust; D – air for gasification; E – water steam for gasification; F – atmospheric air; G – fuel synthesis gas; H – GTE exhaust; J – overheated water steam; L – feed water USG; O – purging oxygen; P – fresh water; S – synthesis gas after the gasifier.

Table 1. Gas turbine parameters

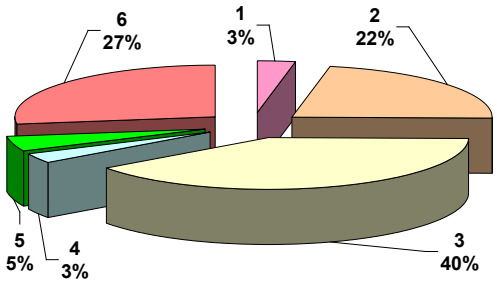
	UGT2500	UGT3200	UGT3200RG
Nominal power, MW	2.85	3.4	3.4
Efficiency. %	28.5	31.5	40.0
Air flow rate, kg/s	14.6	14.9	16.0
Compressor pressure ratio	12	12	7
Exhaust gases temperature after	713	733	-
Gas temperature after regenerator, K	-	-	603
Overall dimensions, m	3.0×1.2×2.0	4.2×2.1×2.3	7.6×2.9×4.2

Table 2. Power plant characteristics

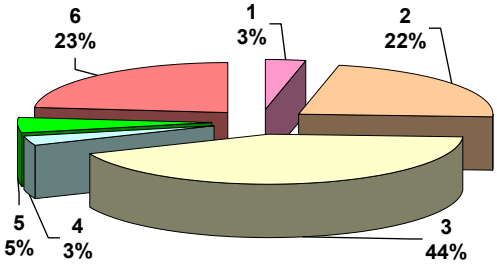
Gas turbine type	UGT3200		
Gasification media	**Air**	**Oxygen**	**Oxygen-steam**
Gas turbine energy output, kW	4412.0	3251.4	3260.0
Energy output from a heat recovery steam unit	1924.4	1447.5	1426.5
Total energy output, kW	6336.4	4698.9	4686.5
Energy consumption for heat recovery unit 1 operation, kW	36.5	31.7	30.7
Energy consumption for heat recovery unit 2 operation, kW	13.2	6.2	6.9
Energy consumption for plasma torches, kW	351.8	272.1	259.4
Power of a synthesis gas compressor, kW	1422.8	492.6	497.3
Power of air blower, kW	129.5	34.6	33.0
Energy for coal grinding, kW	77.4	59.9	57.1
Energy for oxygen production and feeding, kW	0.0	335.3	271.1
Total energy balance for the plant needs, kW	2031.2	1232.3	1155.3
Electrical energy output, kW	4305.2	3466.5	3531.2
Power plant efficiency	0.2811	0.2927	0.3127



Air gasification



Oxygen gasification



Oxygen-steam gasification

Fig.2. Structure of the energy balance in a power plant with UGT3200 gas turbine: 1 – energy consumption of the heat recovery units 1 and 2; 2 – energy consumption of the plasma torches; 3 – SG compressor power; 4 – air blower power; 5 – energy for coal grinding; 6 - energy for oxygen production and feeding

3. Total efficiency of the coal conversion into electric power using direct flow gasification and plasma process initiation could be in the range of 25…36% depending on the GTE performance and gasification method.

4. The best results could be obtained with the SG produced in a plasma gasifier with water steam and oxygen as the oxidants.

5. Net electrical power generation could be in the range of 90…125% of the GTE ISO power capacity and heat recovery contributes 20…30% of the total power.

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Parametric Analysis of Using Thermal Plasma Produced Syngas from Coal for the Engine Combustion Enhancement and for Iron Ore Direct Reduction

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The prospects of technologies for plasma gasification of coal and other solid fuels, that were studied last years [1]-[3], are significantly affected by the integration level with succeeding system of syngas product using. Our research is focused on the analysis of two possibilities for this based on thermodynamic and kinetic methods for such case as Brazilian coal feedstock' treatment [3]. As the first of these variants the assessment of operating parameters for syngas mixture fueled ICE was fulfilled for case of diesel engines for vehicles and power engineering.

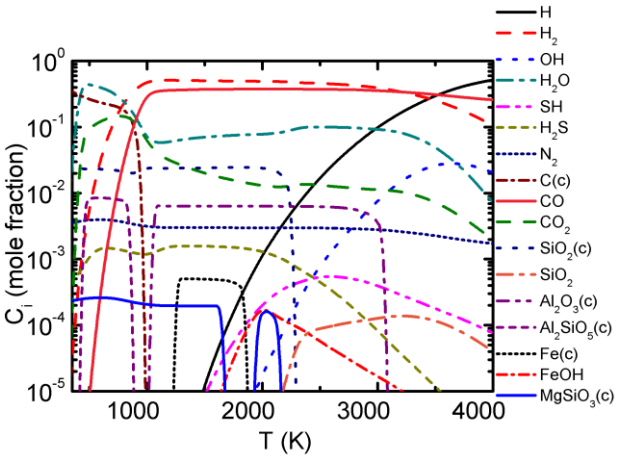


Fig.1. Calculated chemical composition of main gas and solid products for the optimal thermodynamic conditions of thermal plasma steam gasifier with coal feedstock at ratio of reagents G_{STEAM}/G_F = 0.7 and P = 0.1 MPa

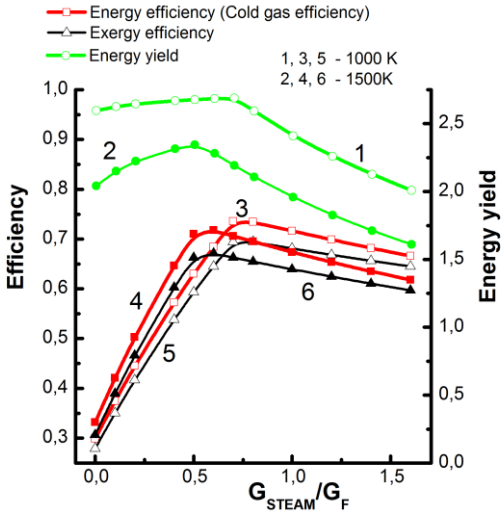


Fig. 2. Results of thermodynamic equilibrium calculation of exergy efficiency and energy one (cold gas efficiency) and energy yield for the model conditions of thermal plasma steam gasifier with subbituminous coal feedstock at P = 0.1 MPa

Table 1. The parameters of serial scale engines for simulation with mixed (syngas+diesel) fuel

Bore **mm**	**Stroke mm**	**Compression ratio**	**Power kWt**	**Engine Speed rpm**	**Fuel Consumption kg/h**	**Pressure aspiration MPa**	**Inject duration CA^0**
127	160	13	25	1800	73	0.25	15
			387	1800	8	0.12	10.8

Based on the recent investigation of especial process for recuperation of diesel exhaust it was shown [4] that is possible to use efficiently the exhaust' oxidation potential at T ≈ 1400 K for carbonaceous feedstock gasification with exergy efficiency level near 28%. Then to determine engine parameters under the operation with syngas addition to liquid fuel the commercial Scania-type engine (see the Table 1), that is used for Brazilian power engineering systems based on diesel generators (e.g. SCANGEN SGE400 with 400 kW maximum power), was simulated under different modes, including the exhaust partial recirculation ones. The composition of syngas was chosen on the experimental data for steam-nitrogen plasma gasification [2] as typical variant for industrial low grade coal feedstock: 51.1 vol. % H_2, 34.1 % CO and 14.8 % N_2. This composition is quite similar to the one for designed last period systems for gasification of low grade solid fuels and wastes, including lignite and subbituminous coals of US, Russia and others [1]–[3]. As the example in Fig.1 the calculated typical syngas composition is presented, that can be produced especially under steam gasification of commercial grade Brazilian coal and related feedstock [3]. The data on Fig.2 also shows the dependences of energy and exergy efficiencies and total "energy yield" [5] vs. ratio of mass flow rates of steam gasifying agent to coal feedstock, that indicate to such preferable for efficiency improvement regimes as ones with the ratio level near of 0.7 kg/kg at averaged for gasification zone temperature T = 1000 K. Based on this regimes it's suitable to optimize the operation of integrated with the coal gasifier in series engine or other syngas utilization system, for example, metallurgical melting unit fore ore direct reduction [6].

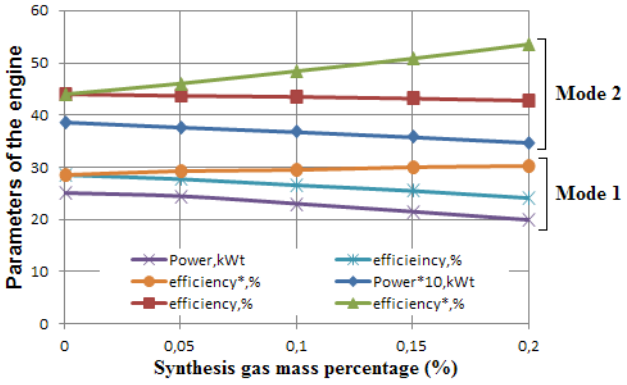


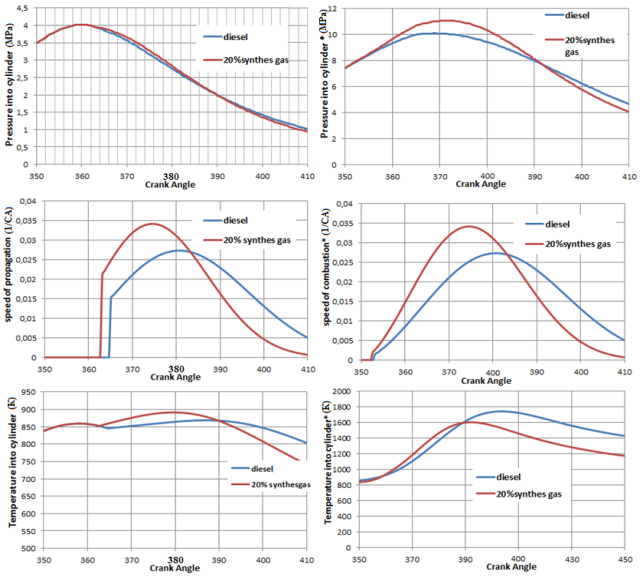
Fig. 3. Simulated diesel engines parameters. «Efficiency» is an efficiency of the engine, that fueled with syngas addition without recuperation. «Efficiency» is for engine mode with syngas partial recuperation. Mode 2 is the regime for high power Scania-type engine operation.*

Under the modeling of the workflow diesel engine was partially used our method [7]. Also with the using the new physical model of combustion process it was found that the combustion process into the engines with the addition of syngas is homogeneous-diffusion process, which is dominated by homogeneous component. Based on these considerations, for the calculation of dimensionless combustion intensity $dx/d\theta$ the kinetic equation of Miyamoto et al. [8] was used:

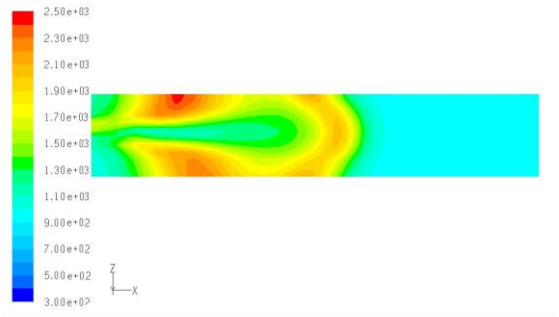
$$\frac{dx}{d\theta} = \alpha_1 \beta \frac{M_p + 1}{\theta_p} \left(\frac{\theta}{\theta_p} \right)^{M_p} \exp\left(-\alpha_2 \left(\frac{\theta}{\theta_p} \right)^{M_p + 1} \right) + \alpha_2 \beta \frac{M_d + 1}{\theta_d} \left(\frac{\theta}{\theta_d} \right)^{M_d} \exp\left(-\alpha_2 \left(\frac{\theta}{\theta_d} \right)^{M_d + 1} \right). \quad (1)$$

where the subscripts, *p* and *d* refer to premixed and diffusive combustion parts, M_p and M_d are shape factors, θ_p and θ_d are the energy release duration, α_1 and α_2 are empirical constants.

The modeling results for main engines parameters are shown in Fig.3 and indicates 10% rise of efficiency for mode 2 (53% vs. 43%). Other results (cylinder pressure (CP), its temperature (CT) and combustion intensity with mixed fuel) are presented in Fig.4a-b. These results show that syngas addition to diesel increases maximal CP by 1 MPa and CT by 200 K for the engine under high boosted mode. In addition for the verification of data obtained we modeled the same case of engine operation with mixed fuel, but with syngas composition from the thermodynamic calculation of coal steam gasification in optimal regime (see Fig.1). This syngas contains 50.7 % H_2, 33.2 % CO, 6.3 % CO_2, 6.7 % H_2O. Ultimately it was found that 20% syngas addition to the SGE400 engine resulted in power rise by 8.7% and its efficiency level was such as 38.4–43 %.



(a) (b)



(c)

Fig. 4. Results of kinetic and CFD simulation of processes in the diesel engine; a) mode 1 (table 1); b) mode 2 (table 1); c) 3D simulation result of flame propagation in the cylinder

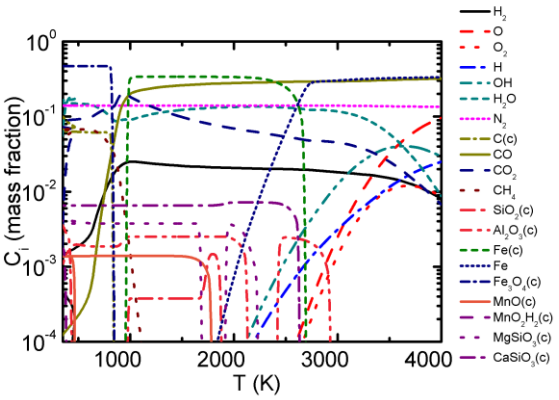


Fig.5. Calculated chemical composition of the products of direct reduction (at P = 0.1 MPa) of Brazilian iron ore pellets with syngas produced from steam plasma gasification of coal. Fe (c) – condensed (liquid/solid) iron phase (i.e. main product of the process). The ratio of mass flow rates of ore feedstock to the syngas is 1.0.

The one related problem for the syngas application is the process for iron ore reduction, which was actively designed last decades. To analyze this we need to estimate the optimal process parameters for high yield of the product. Fig. 5 shows the results of thermodynamic calculation for optimal regime of Brazilian iron ore (pellets [9]) direct reduction (with the

same syngas composition [2]), that indicate to ~100% degree of reduction to metal iron near its melting point [6]. So, this syngas from coal can be considered as the reductant with high potential for metallurgical processes.

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Economics on Application of the RF/IC Plasma Systems

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Feasibility of every plasma based technology should be considered for the entire product life cycle. In this case initial cost of ownership, which is normally higher for new products, will be compensated by advantages of new technology, as higher quality and productivity, lower operational costs, and others.

Economics of the plasma part of a new technology in case of the Radio Frequency (RF) or Inductively Coupled Plasma (ICP) based systems should consider two main factors: (1) **cost of ownership** and (2) **operating cost**. Cost of ownership is mainly a function of the production expenses and the only way for their reduction is mass production. For example, cost of a 1 kW magnetron for a MW oven is about $10 only due to millions to be fabricated each year.

Operating cost depends on many factors, mostly on the entire plasma system efficiency, supplies, maintenance, and reliability. It could be seen that even 10-20% differences in efficiency @ 100 kW power level with cost of electricity $0.1 per kW x hour leads to $2 per hour losses or gain (see table below for major plasma systems efficiency comparison). This may effect economics only in a long term perspective. At the same time maintenance might be the key issue particularly for that plasma devices which contain critical elements with relatively short lifetime, as cathodes and anodes. In this case RF plasma systems with electrodeless design are the best candidates for such technologies as coal and waste gasification, new materials sintering, etc., which need thousands of hours of non-stop operation.

Type of Plasma System	Power Supply + Waveguide, %	Torch, %	Total Efficiency, %
ICP 1st generation	60 - 65	70 - 75	42 - 48
DC	85 - 90	65 - 75	55 - 67
ICP 2nd generation	60 - 90	90 - 95	54 - 86
MW	70 - 75	90 - 95	63 - 72

Technology for Tire's Waste Processing into the Alternative Liquid Fuels

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National University of Shipbuilding, Mykolayv, Ukraine

At present time used tire's waste stored in huge amount around the world and pollutes an Environment. For instance, USA forms up to 2,000,000 tons of used tire waste annually. Processing of this waste is technically complicated, needs a special equipment, sophisticated environment protection facility and much expensive enough.

Huge amount of the stored used tire's waste is the significant fire and hazard contamination threat to the environment (Fig.1 and Fig.2)

Fig.1 Stored used tires at the garbage

Fig.2 Fire and environment contamination

The environment-friendly and energy effective technology has elaborated in the Center of the Advanced Energy Technology in National University of Shipbuilding, Ukraine. Its principle scheme is sown on Fig. 3. The main goals of this technology are to process used tires whole without crushing and get commercial products: artificial gasoline or light diesel oil, carbon black and metal cord as a scrap.

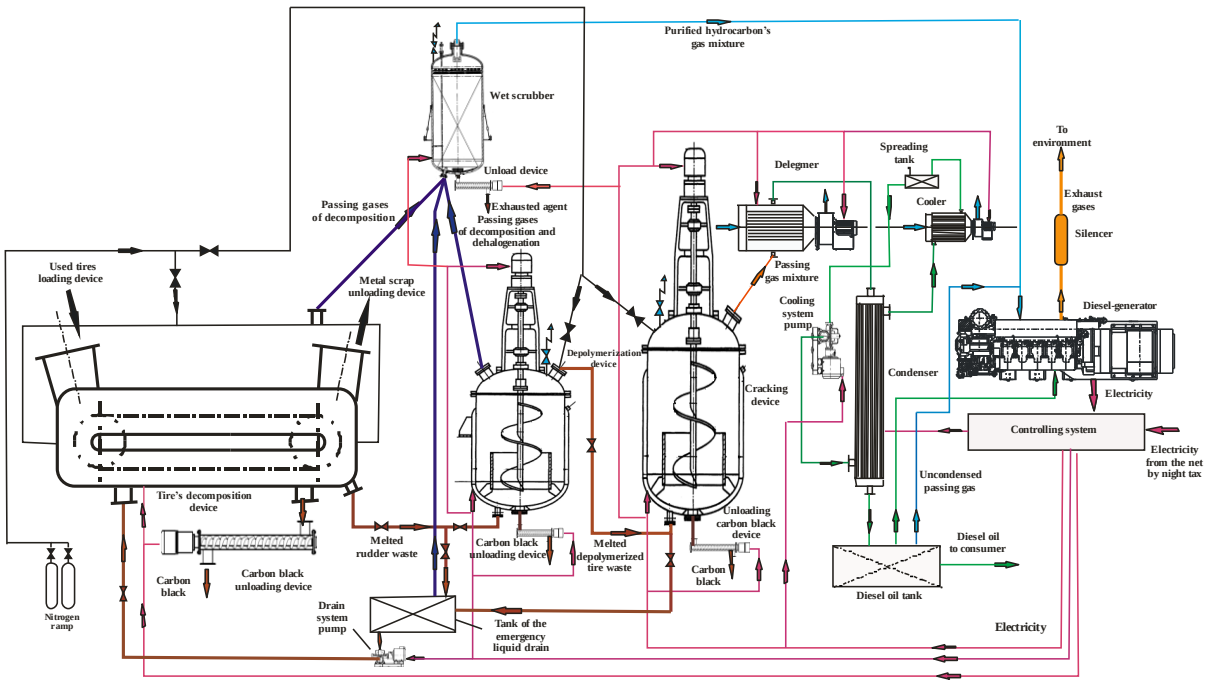

Fig.3 The principal technological scheme of the used tire's waste processing into artificial fuels

The main principle of this technology is continuous decomposition of the used tires in conveyor reactor, and hydrocarbon liquid formation, and controlled thermo-cracking process of the hydrocarbon liquid in to commercial products.

Preliminary experimental researches allow obtain the yield (%) of these products, which are shown in Table 1.

Table 1. The experimental facility product's output (%, mass)

Temperature, °C	Yield, %						
	Gasoline	Light diesel oil	Passing gas	Carbon black	Metal scrap	Total	Process Supply[1]
410	33,2	7,4	10,6	35,0	13,8	100,00	5,9
506	27,5	6,1	12,9	39,7	13,8	100,00	8,8
620	21,1	5,2	14,4	45,5	13,8	100,00	12,1
[1] – %, from total product's yield (gasoline & passing gas)							

Processing pollution provided by systems for chemical dehalogenation, desulfurization and final treating of the exhaust gases with advanced plasma technology elaborated and supplied by Applied Plasma Technologies (APT) Corporation.

The preliminary project estimations allow obtain the main indexes of the used tire's waste processing facility capacity of 3000 t/year which are shown in Table 2.

Table 2. Average main project indexes

##	Indexes	Value
1	Capacity of the plastics waste processing, t/year	3000
2	Gasoline, t/year	996
3	Light diesel fuel, t/year	222
4	Passing gas, t/year	31,8[2]
5	Carbon black, t/year	1050
6	Metal scrap, t/year	414
[2] – 5,9 % of this amount uses for process energy supply		

Conclusion

Rubber tire's waste processing technology is energy effective, environment friendly. Preliminary researches and development allow conclude that this technology can be safely implemented for industrial purposes.

Announcing a Special Issue of the IEEE Transactions on Plasma Science Plasma-Assisted Combustion (Scheduled for December 2013)

The Technical Committee on Plasma Science and Applications of the IEEE Nuclear and Plasma Science Society along with the Guest Editors invite contributions to the Special Issue of the IEEE Transactions on Plasma Science on Plasma-Assisted Combustion to appear in December 2013.

The application of plasmas to enhance combustion processes is an emerging field of plasma science and technology. It is lately receiving considerable interest, driven by the need for more energy-efficient and less-polluting combustion techniques. A special forum for scientists and researchers to disseminate and review the current research and applications in this field is needed. Work in the field of plasma-assisted combustion has been reported in diverse journals and related media, and a past special issue (December 2012) has provided the needed special forum. The IEEE Transactions on Plasma Science provides an archival domain for the publication of new scientific, technological, and application results in plasma science and technology.

The intention of this Special Issue is to provide an integrated forum for high-quality publications in the field and to promote further interest and exchange of technical information in this exciting and technologically important area of plasma science. Contributions are solicited in, but not restricted to, the following topics:

- Ultra-low sulfur content
- Physics/chemistry of effects of plasmas on flames and deflagration-to-detonation transition.
- Use of plasmas to promote and/or improve efficiency in engines (automotive, aircraft, etc.) or flames and/or burners.
- Plasma sources (e.g., jets) for improved ignition.
- Applications to aircraft pulsed detonation engines.
- Applications to pollution reduction (i.e., combustion efficiency improvement - not exhaust cleaning).
- Applications to fuel reforming/conversion (e.g., fossil fuel to hydrogen).

Both full-paper and shorter technical-note manuscripts will receive consideration for publication in this Special Issue.

All contributions should reach the Guest Editors **no later than May 1, 2013** at the IEEE Transactions on Plasma Science IEEE Manuscript Central website at http://tps-ieee.manuscriptcentral.com. Questions regarding the Special Issue on Plasma-Assisted Combustion can be addressed to the Guest Editors:

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