4th International Workshop and Exhibition on Plasma Assisted Combustion (IWEPAC)

16-19 September 2008
Best Western Falls Church Inn
Virginia, USA

Applied Plasma Technologies
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FUEL REFORMATION AND ACTIVATION

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PLASMA EFFECTS AND PERSPECTIVE APPLICATIONS

Synopsis

Among about 110 Plasma Conferences to be held in 2008, IWEPAC is the only one devoted to the field of Plasma Assisted Combustion (PAC).

Established in 2003, IWEPAC provides a specialized forum for researchers, industry experts and venture capitalists to present and discuss scientific, engineering and marketing aspects of PAC, thereby advancing the field to help address critical energy, propulsion, pollution, and climate issues of the 21st century.

IWEPAC-4 will have five separate sessions: (1) plasma ignition and flame control; (2) plasma generation and modeling; (3) fuel reformation and activation; (4) waste-into-energy processing; and (5) new plasma effects and perspective applications. 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. An additional session will be devoted to open discussion of the International Plasma Technology Center concept, objectives and main positions.

IWEPAC-4 is expected to have from 30 to 35 oral presentations (30 minutes in duration, including questions and answers) and a half-day exhibition of PAC technology and hardware. The exhibition is a very attractive event within IWEPAC. Participants will be encouraged to demonstrate the operation of technical and engineering prototypes and commercial equipment. Several operating plasma devices, including nano-second rise-time discharge spark plugs, subsonic and supersonic plasma igniters, multi-mode plasma pilot devices (combustion sustainers), microwave and hybrid type plasma torch (RF + transient DC) with reverse vortex flows, plasma assisted "Tornado" combustors and fuel reformers will be demonstrated at the exhibition area of the IWEPAC-4.

IWEPAC-4 will be held September 16 to 19 in the Best Western Falls Church Inn, Ball Room, 6633 Arlington Blvd, Falls Church, Virginia 22042, U.S.A. (Washington, D.C. area). During the workshop, we plan to establish an International Council of Experts in the field of PAC, to start working on the National PAC Roadmap to provide an integrated plan to advance the field, and to provide support to junior scientists and select papers for publication in the *IEEE Transactions on Plasma Science* Special Issue on Plasma-Assisted Combustion.

IWEPAC-4 proceedings will be available in two formats: color booklet with abstracts and after-meeting DVD. The cost is included in the registration fee.

IWEPAC – 4
Tentative Agenda

Monday, 15 September

16.00 – 18.00	Registration, Best Western Falls Church Inn Lobby 6633 Arlington Blvd, Falls Church, VA 22042, USA Phone: (1-703) 532-9000, fax: (1-703) 532-3887

Tuesday, 16 September

8.00 – 10.00	Registration, Ball Room
9.00 – 9.45	**IWEPAC-4 OPENING** Welcome remarks from: *Dr. Igor Matveev* (Applied Plasma Technologies) *Dr. Phillip Westmoreland, Program Director* (National Science Foundation) *Dr. Louis Rosocha* (Los Alamos National Laboratory, DOE and Applied Physics Consulting)
9.45 – 10.00	Break
10.00 – 17.00	**PLASMA IGNITION AND FLAME CONTROL** Chaired by *Dr. Igor Matveev*, Applied Plasma Technologies, USA
10.00 – 10.30	**Plasma Ignition System for Internal Combustion Engines “Plasma Drive”** *Lonnie Lenarduzzi* (Plasmatronics, LLC, USA)
10.30 – 11.00	**Test Results of the Non-thermal Plasma Ignition System for Internal Combustion Engines** *Lonnie Lenarduzzi* (Plasmatronics, LLC, USA) *Dr. Albina Tropina, Alexander Panikarsky, Vladimir Bozhenov* (Kharkov National Automobile and Highway University, Ukraine)
11.00 – 11.15	Break
11.15 – 11.45	**Lifted Flame Speed Enhancement by Ozone** *Timothy Ombrello, Dr. Sang Hee Won and Prof. Yiguang Ju* (Princeton University, USA) *Dr. Skip Williams* (Air Force Research Laboratory, Propulsion Directorate, Wright-Patterson AFB, USA)

11.45 – 12.15	**Liftoff and Blowoff of Nonpremixed Laminar Jet Flames in Electric Fields** *Dr. S. H. Won, S. K. Ryu, M. K. Kim, S. H. Chung* (School of Mechanical and Aerospace Engineering, Seoul National University, Seoul 151-742, Korea) *Dr. M. S. Cha* (Korea Institute of Machinery & Materials, Daejeon, Korea)
12.15 – 13.30	Lunch
13.30 – 14.00	**Subcritical Streamer Microwave Discharge in Reverse Vortex Combustion Chamber** *Prof. K. V. Aleksandrov, Prof. V. L. Bychkov, L. P. Grachev, Dr. Igor I. Esakov, Prof. Kirill V. Khodataev, Dr. Alexander A. Ravaev* (Moscow Radiotechnical Institute of the Russian Academy of Sciences, Moscow, Russia) *Dr. I.B. Matveev* (Applied Plasma Technologies, USA)
14.00 – 14.30	**Development and Preliminary Test Results of the Supersonic Plasma Igniter** *Dr. Igor Matveev* (Applied Plasma Technologies, USA) *Evgeniy Kirchuk* (Plasma Technika Consult, Ukraine)
14.30 – 14.45	Break
14.45 – 15.15	**Air-propane Mixture Ionization for Optimization of Ignition at Application of Gas Discharges** *Prof. Vladimir L. Bychkov, Dmitriy V. Bychkov* (Moscow Radiotechnical Institute of the Russian Academy of Sciences, Russia) *Dr. I.V. Kochetov* (State Research Center, Troitsk Institute for Innovation and Thermonuclear Research, Russia)
15.15 – 15.45	**Plasma-Assisted Ignition and Combustion of Hydrocarbon Fuel in High-Speed Airflow by HF Streamer Discharge** *Dr. Anatoliy Klimov, Ivan Moralev, Boris Tolkunov* (Joint Institute of High Temperature RAS, Russia) *Dr. Igor Matveev* (Applied Plasma Technologies, USA)
15.45 – 16.00	Break
16.00 – 17.00	Round Table on Plasma Ignition and Flame Control
17.00 – 20.00	*Greeting Members of the International Council of Experts in Plasma Assisted Combustion* Welcome Party (Ball Room)

Wednesday,17 September

9.00 – 11.30	**EXHIBITION** 5408 Port Royal Rd., Unit S, Springfield, VA 22151 – APT Laboratory http://www.plasmacombustion.com/directions.htm Transportation from Best Western Falls Church Inn provided
12.00 – 13.30	Lunch
13.30 – 17.15	**PLASMA GENERATION, DIAGNOSTICS, AND MODELING** Chaired by *Professor Homero Maciel*, Instituto Tecnologico de Aeronautica, Brazil
13.00 – 13.25	**Atmospheric Pressure Reverse Vortex Microwave Plasma Generator** *Boris P. Lavrov, Pavel B. Lavrov, Alexander A. Ravaev, Kirill V. Khodataev, Vladimir L. Bychkov, Lev P. Grachev* (Moscow Radiotechnical Institute of the Russian Academy of Sciences, Moscow, Russia) *Dr. Igor Matveev* (Applied Plasma Technologies, USA)
13.25 – 13.50	**Longitudinal Plasmoid in High-Speed Vortex Gas Flow Created by Capacity HF Discharge** *Dr. A. Klimov, K. Minko, I. Moralev, M. Plotnikova, B. Tolkunov* (Institute for High Temperature of the Russian Academy of Sciences, Moscow, Russia)
13.50 – 14.00	Break
14.00 – 14.25	**Experimental Investigations of the Hybrid Plasma Torch with Reverse Vortex Stabilization** *Dr. Sergey Zverev, Dr. Dmitry Ivanov, Prof. Vladimir Frolov* (Saint-Petersburg State Polytechnic University, Russia) Dr. *Igor Matveev* (Applied Plasma Technologies, USA)
14.25 – 14.50	**Calculation of the Main Parameters of Inductively Coupled Plasma Torches for Technological Applications** *Dr. Sergey Zverev, Dr. Dmitry Ivanov* (Saint-Petersburg State Polytechnic University, Russia)
14.50 – 15.00	Break
15.00 – 15.25	**Excitation of the Microwave Torch Discharge in a Single Conductor Line** ***Alexey Kuleshov***, *Boris Efimov, Maxim Khorunzhiy* (Institute of Radiophysics and Electronics of the National Academy of Sciences of Ukraine)

15.25 – 15.50	**Numerical Analysis of a Nanosecond Discharge Dynamics** *Dr. Albina Tropina* (Kharkov National Automobile and Highway University, Ukraine)
15.50– 16.15	**Spectroscopic Diagnostics of Atmospheric Pressure Plasmas** *Dr. Yongho Kim, Dr. Louis Rosocha, Jaeyoung Park, Graydon Anderson, Sara Abbate, Tsitsi Madziwa-Nussinov, Vincent Ferreri, Keenan Pepper* (Los Alamos National Laboratory, USA) *Sang Hee Hong, Ji Hun Kim* (Seoul National University, Korea) *Young Hoon Song* (Korea Institute of Machinery and Materials, Daejeon, Korea)
16.15– 16.30	Break
16.30 – 17.15	Round Table on Plasma Generation, Diagnostics, and Modeling
17.15 – 17.30	Break
17.30 – 19.30	**INTERNATIONAL PLASMA TECHNOLOGY CENTER - CONCEPT, OBJECTIVES AND MAIN POSITIONS** **Open Discussion** Speaker – *Dr. Igor Matveev,* Applied Plasma Technologies, USA

Thursday, 18 September

9.00 – 15.30	**FUEL REFORMATION AND ACTIVATION** Chaired by *Dr. Louis A. Rosocha,* Applied Physics Consulting, USA
9.00 – 9.30	**Non-Thermal Plasma Hydrocarbon Cracking With Novel Electrode and Dielectric Arrangements** *Dr. Louis A. Rosocha* (Applied Physics Consulting, USA) *Dr. Yongho Kim* (Los Alamos National Laboratory, USA)
9.30 – 10.00	**Experimental Investigation of the Hybrid Type Plasma Assisted Combustion and Reformation System** *Dr. Igor Matveev* (Applied Plasma Technologies, USA) *Prof. Serhiy Serbin* (National University of Shipbuilding, Ukraine)

10.00 – 10.30	**Theoretical Investigation of the Physical and Chemical Processes in a Liquid Fuel Plasma Assisted Reformer** *Dr. Igor Matveev* (Applied Plasma Technologies, USA) *Prof. Serhiy Serbin, Kateryna Serbina* (National University of Shipbuilding, Ukraine)
10.30 – 10.45	Break
10.45 – 11.15	**Study of Plasma Conversion of Ethanol into Syngas in Dynamic Plasma-Liquid Systems** *Chernyak V.Ya., Olzhevskij S.V., Yukhymenko V.V., Prisyazhnevich I.V., Verovchuck M.A., Solomenko E.V., Zrazhevskij V.A., Naumov V.V.* (Taras Shevchenko Kyiv National University, Ukraine) *Shchedrin A.I., Levko D.S.* (Institute of Physics, Ukrainian Academy of Sciences, Ukraine) *Demchina V.P., Kudryavzev V.S.* (Institute of Gas, Ukrainian Academy of Sciences, Ukraine)
11.15 – 11.45	**Application of Different Oxidants for Plasma Coal Gasification** *Dr. Igor Matveev* (Applied Plasma Technologies, USA) *Prof. Vladimir E. Messerle* (Research Institute of Experimental and Theoretical Physics, Kazakhstan) *Dr. Alexander B. Ustimenko* (Research Department of Plasmotechnics, Kazakhstan)
11.45 – 12.15	**Plasma-Fuel Systems for Coal Fired Thermal Power Plants** *Prof. Evgeniy I. Karpenko* (Branch Centre of Plasma-Power Technologies of the Russian J.S.Co. "UPS of Russia", Gusinoozersk, Russia) *Dr. Igor Matveev* (Applied Plasma Technologies, USA) *Prof. Vladimir E. Messerle* (Research Institute of Experimental and Theoretical Physics, Kazakhstan) *Dr. Alexander B. Ustimenko* (Research Department of Plasmotechnics, Kazakhstan)
12.15 – 13.30	Lunch
13.30 – 14.00	**Studies of Plasma Assisted Coal Gasification for Syngas Production** *Prof. Homero S. Maciel, G. Petraconi, A.S. da Silva Sobrinho, R.S. Pessoa, J.C Sagás and A. Pereira Filho* (Instituto Tecnológico de Aeronáutica, S.J. Campos, Brazil)

14.00 – 14.30	**Mass Spectrometry Studies of Partial Oxidation of Methane in a Gliding Arc Reactor** *Prof. Pedro T. Lacava , Prof. Homero S. Maciel, G. Petraconi, A.S. da Silva Sobrinho, R.S. Pessoa, J.C Sagás and A. Pereira Filho* (Instituto Tecnológico de Aeronáutica, S.J. Campos, Brazil)
14.30 – 14.45	Break
14.45 – 15.30	Round Table on Fuel Reformation and Activation
15.30 – 15.45	Break
15.45 – 19.00	**WASTE - TO - ENERGY PROCESSING** Chaired by *Mr. Rod Vera*, Plasma Waste Recycling, USA
15.45 – 16.15	**Gasification of Solid Fuels Using Entrained Plasma Reactor** *Prof. Vladimir E. Messerle* (Research Institute of Experimental and Theoretical Physics, Kazakhstan) *Dr. Alexander B. Ustimenko* (Research Department of Plasmotechnics, Kazakhstan)
16.15 – 16.45	**High Capacity MSW Processing Technology** *Mr. Rod Vera* (Plasma Waste Recycling, USA)
16.45 – 17.00	Break
17.00 – 17.30	**Alternative Solutions for MSW-To-Energy Processing** *Dr. Igor Matveev* (Applied Plasma Technologies, USA)
17.30– 18.00	**Benefits of Solid State Technology in Modern Power Supplies** *Kris Livermore* (Thermatool Corp., USA)
18.00 – 18.15	Break
18.15 – 19.00	Round Table on Waste-To-Energy Processing

Friday, 19 September

9.00 – 12.30	**NEW PLASMA EFFECTS AND PERSPECTIVE APPLICATIONS** Chaired by *Mr. Zbigniew Zurecki*, Air Products and Chemicals, Inc., USA
9.00 – 9.30	**Perspective Plasma Technologies. Overview, Technical and Economical Advantages, Market Values** *Dr. Igor Matveev* (Applied Plasma Technologies, USA)

9.30 – 10.00	**Energy-Saving Electromagnetic Reactor For Mineral Materials Melting** *Prof. Evgeniy I. Karpenko* (Branch Centre of Plasma-Power Technologies of the Russian J.S.Co. "UPS of Russia", Gusinoozersk, Russia) *Dr.V.G.Lukiaschenko, Prof. Vladimir E. Messerle* (Research Institute of Experimental and Theoretical Physics, Kazakhstan) *Dr. Alexander B. Ustimenko* (Research Department of Plasmotechnics, Kazakhstan)
10.00 – 10.30	**Treatment of Contaminated Soil in Serbia Using Plasma Technology** *Dr. Petar Rakin, Dr. Zoran Stevic* (IHIS Science & Technology Park Zemun, Belgrade, Serbia)
10.30 – 10.45	Break
10.45 – 11.15	**Application of Non-equilibrium Arc Discharges for Activation and Modification of Reactive Atmospheres Used in Metal Heat Treatment Operations at 1 Atmosphere Pressure** *Dr. Shailesh P. Gangoli and Zbigniew Zurecki* (Air Products & Chemicals, Inc., USA)
11.15– 11.45	**Treatment of Exhaust Gases from Industrial and Automotive Sources Using Non Thermal Plasmas** *Dr. Louis A. Rosocha* (Applied Physics Consulting, USA)
11.45 – 12.00	Break
12.00 – 12.30	Round Table on New Plasma Effects and Perspective Applications Conference Closing
12.30 – 13.30	Lunch
13.30 – 16.00	**DISCUSSIONS, NEGOTIATIONS, ADDITIONAL PROTOTYPES DEMONSTRATION TO POTENTIAL CUSTOMERS** **In the APT Laboratory**

Plasma Ignition System for Internal Combustion Engines "Plasma Drive"

*Lonnie Lenarduzzi, Chief Scientist**
Plasmatronics, LLC, USA

A nanosecond range plasma discharge ignition system has been created called the Plasma Drive Ignition® or PDI for short. This ignition system has been fitted to gasoline powered internal combustion engines for the purpose of improving engine performance, reducing fuel consumption and reducing tail pipe emissions.

After years of testing the PDI by both company scientists and independent third party testing facilities, a great deal of information about the effects of plasma ignition on the internal combustion engine has been amassed. Among these findings concerns the relationship between hydrocarbons (HC) and oxides of nitrogen (NOx) in the exhaust stream of the engine. When engine parameters are changed in a conventional spark ignited engine, as HC increases, NOx decreases and as HC decreases, NOx increases. The seesaw relationship between HC and NOx is reversed by the PDI: as HC decreases, so does NOx. This phenomenon is attributed to lower exhaust gas temperatures that have been observed in engines equipped with plasma ignition.

It has been observed that the PDI increases the size of the flame kernel significantly over spark ignition. The resultant increase in combustion efficiency yields increases in fuel economy and engine power. Fuel efficiency gains of 28% have been realized in large displacement engines used under continuous heavy load conditions. Plasma ignition makes lower fuel/air ratios possible. Light duty, small displacement engines tuned for maximum fuel efficiency with spark ignition has shown a 7% increase when retuned with the PDI installed.

Below is a chart showing the range of engine improvements observed with the PDI versus conventional spark ignition.

Measure	Decrease in Vehicle Emissions	Increase in Fuel Economy	Increase in Vehicle Power
Hydrocarbons (HC)	35-44%		
Carbon Monoxide (CO)	18-24%		
Oxides of Nitrogen (NO_x)	45-52%		
Carbon Dioxide (CO_2)	18-22%		
Fuel Economy (mpg)		+ 7-28%	
Horsepower (hp)			+ 5-11 %

The PDI has reached the mass production stage of development and has been designed for low cost machine assembly. The first test runs of machine assembled PDI units have been completed and have passed SAE standardized testing for under hood electronics.

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Test Results of the Non-thermal Plasma Ignition System for Internal Combustion Engines

*Lonnie Lenarduzzi, Chief Scientist**
Plasmatronics, LLC, USA

*Albina Tropina**, Alexander Panikarsky, Vladimir Bozhenov*
National Automobile and Highway University, Kharkov, Ukraine

The performance of non-thermal plasma ignition by nanosecond discharge and conventional spark ignition were compared in 1.5 liter 4-cylinder engine under identical operating conditions and using 95 octane gasoline. Such parameters as engine RPM, air/fuel ratio, timing were controlled and adjusted during the experiment. The plasma ignition system used for the experiments described here is the Plasma Drive Ignition® system (PDI) [1] manufactured by Plasmatronics®, LLC. Engine efficiency using the PDI as an ignition source was analytically evaluated by the reduced electric field value E/N, where E is the electrical field strength, N is the concentration of neutral gas molecules. It is known that the rate constants of ionization reaction, electron and oscillatory excitation and molecular dissociation by electron impact have very strong exponential dependence on reduced electric field. Increasing the interactions of electrons and fuel/air molecules results in greater numbers of chemically active particles responsible for combustion initiation.

The main characteristics of the signal formed by the PDI system such as duration, rise time and maximum voltage were analyzed and compared with analogous nanosecond discharge. It has been shown that at two electrodes configuration with inter electrode spacing $d_o=10^{-3}\ m$, initial gas temperature $T_o=700^oK$ and pressure varying in limits $p \div 0.1\text{-}0.4\ MPa$ the reduced electrical field of the discharge created by the PDI system is

$$280\ Td \leq \frac{E}{N} \leq 70\,Td$$

At such high reduced electric field values, the electron levels of molecules are excited and the ignition efficiency is increased.

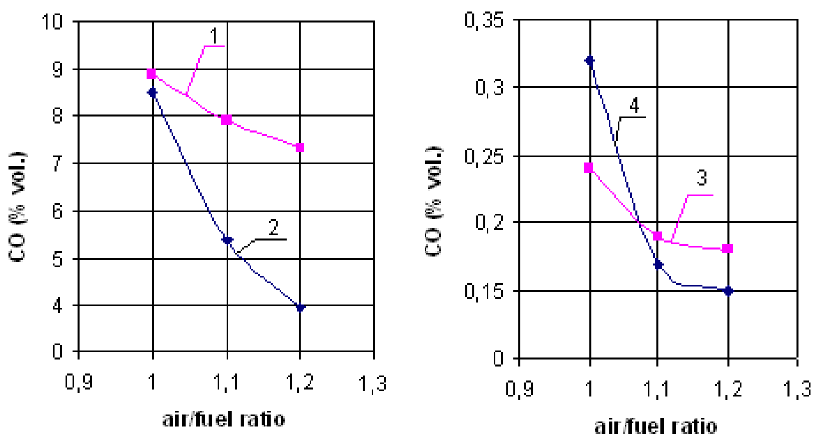

Fig.1. CO fraction in the exhaust gases for different air-fuel ratio and engine RPM: 1,3 - conventional spark ignition, 2,4 - PDI system; 1,2 - RPM=2200, 3,4 - RPM=800

Due to the inherent short duration of the ignition discharge, multiple ignition sites are generated which reduce cycle to cycle variation due to fluctuations of the air/fuel ratio mixing in the discharge volume. Monitoring of the vehicle exhaust gases composition during road tests can experimentally prove improved combustion. The road tests method was as follows; the test vehicle was driven on a closed road in two directions repeatedly at the speed of 60 km/hour with identical climatic conditions. The vehicle trajectory was controlled by GPS. The fuel economy measurement was realized by weight method. Verification of the dynamic characteristics recorded during road tests was carried out by comparing of the automobile acceleration time from 60 km/hour to 100 km/hour for conventional spark ignition and for PDI system. A Sun model MGA 1500S gas analyzer was used to measure the composition of the vehicle exhaust gases. Experiments indicated that for lean mixtures the PDI system has shown much better ecological characteristics than the standard ignition system (see Fig.1, Fig.2). Given equal fuel/air ratios for conventional spark ignition and plasma ignition, the combustion completeness for PDI system increased with engine speed. Varying ignition timing did not improve test results. Road tests revealed fuel consumption was reduced by as much as 7%.

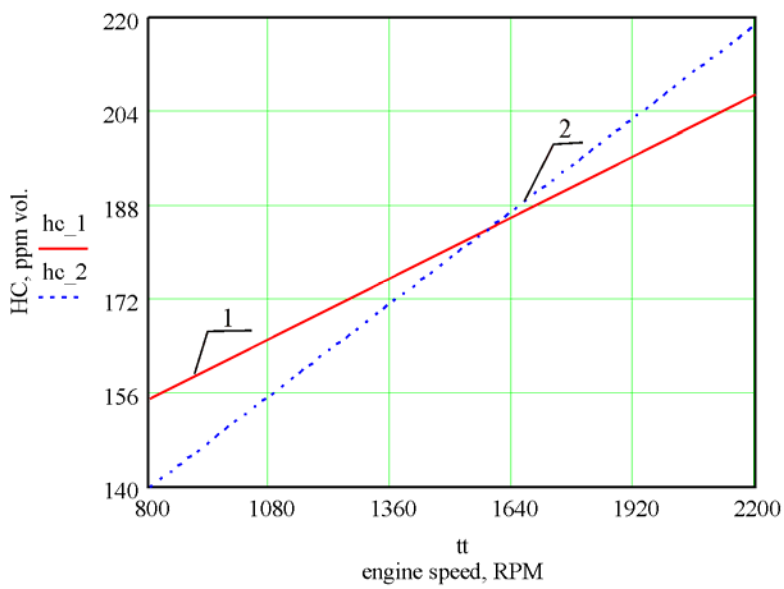

Fig.2. HC fraction in the in the exhaust gases for different engine speed (air-fuel ratio is equal a = 1): 1 - conventional spark ignition, 2 - PDI system

References

1. L. Lenarduzzi. *Plasma Ignition System for Internal Combustion Engines "Plasma Drive".* Abstracts of the 3-rd International Workshop and Exhibition on Plasma Assisted Combustion (IWEPAC) 18-21 September 2007, Falls Church Virginia, USA, P.46.

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Albina A. Tropina *graduated from Kharkov National University (Ukraine), the Mathematical and Mechanical faculty and received a Ph.D. Degree in Mechanics of liquids, gas and plasma in 1999. From 1990 to 1999 she was a Researcher, an Assistant Professor with Kharkov National University. Since 2000 she has been working with Kharkov National Automobile and Highway University as Senior Lecturer, Associate Professor on the department of mechanics and hydraulics. Her research interests are focused on the theoretical investigation of plasma-assisted combustion and combustion at presence of an electric field.*
Research interests: plasma assisted ignition and combustion, mathematical modeling of plasma processes

Alexander Panikarsky - *Associate Professor of the Automobile Electronics Department in Kharkov National Automobile and Highway University (Ukraine), PhD*
Research interests: ecological vehicles, hybrid automobiles

Vladimir Bozhenov - *Post-graduate Student of the Automobile Electronics Department in Kharkov National Automobile and Highway University (Ukraine)*
Research interests: ecological vehicles, hybrid automobiles

Lifted Flame Speed Enhancement by Ozone

Timothy Ombrello, Sang Hee Won and Yiguang Ju
Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, USA

Skip Williams
Air Force Research Laboratory, Propulsion Directorate, Wright-Patterson AFB, USA

Kinetic ignition enhancement by plasma produced O_3 was studied experimentally through the development of a novel low pressure lifted flame apparatus. Motivation for the current work came from addressing the lack of understanding of the kinetic enhancing effects on combustion by plasma produced oxygen species. Our previous work was focused on de-coupling and isolating the enhancing effects of plasma on combustion.[1-3]. The current work served to isolate the effect of individual plasma produced species such as O_3 since little quantitative experimental work on O_3 affected flame speeds has been performed.[4].

Experimentally, a lifted flame burner was installed in a low pressure chamber with C_2H_6 or C_3H_8 as the fuel and O_2 in Ar as the oxidizer co-flow. A schematic of the experimental set-up is shown in Fig. 1. The high velocity fuel jet and low velocity co-flow created a flow-field with a stoichiometric contour where the pre-mixed flame head of a lifted flame was located. Depending upon the balance between the local flow velocity and flame speed in the system, the flame could be either stationary or propagating. Therefore, enhancement could be observed when the flame liftoff height changed or the flame propagated to the nozzle at a different rate.

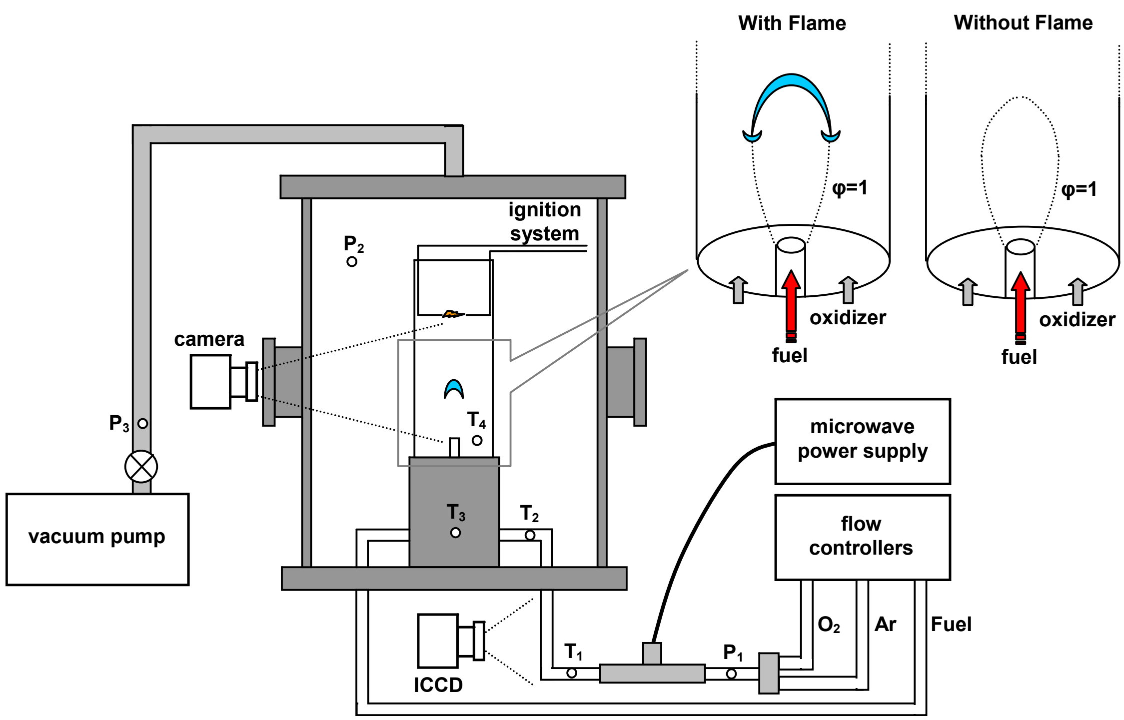

Fig.1. Low pressure lifted flame experimental set-up.

To excite the co-flow of O_2 in Ar and produce species to enhance the combustion in the system, an electrodeless microwave discharge (McCarroll cavity driven by an Opthos MPG-4M microwave power supply) with up to 100 Watts of power was used external to the chamber, upstream of the lifted flame burner. The plasma converted several percent of the O_2 to atomic and excited states such as O, $O(^1D)$, $O(^1S)$, $O_2(^1\Delta_g)$ and O_3. Pressures, O_2 loadings and flow surfaces were chosen to suppress the effect of all species except for O_3.

The results for O_2 loadings of 14% showed that a stationary lifted flame moved closer to the nozzle with plasma activation of the co-flow (Fig. 2), giving several percent enhancement of the flame speed. The temperatures and pressures remained constant in the system when the plasma was on or off, confirming that the flame speed enhancement was strictly kinetic. For O_2 loadings of 18.5%, propagating flame measurements using a high speed camera also yielded results of kinetic flame speed enhancement of several percent.

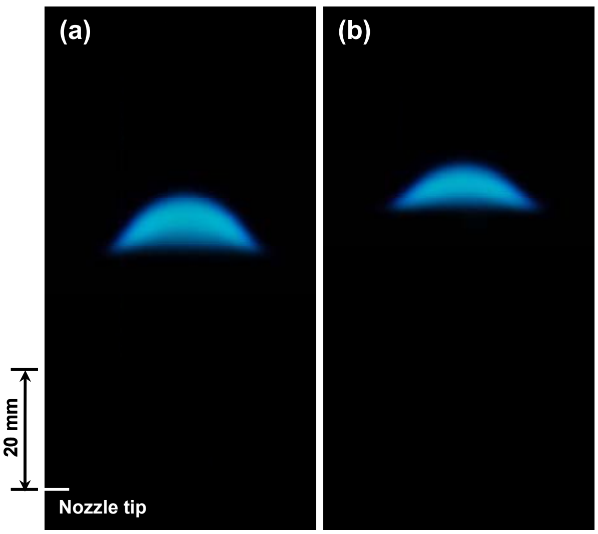

Fig.2. Direct photographs of lifted flame with (a) Plasma On and (b) Plasma Off.

Quantification of the concentrations of O_3 was achieved through experimental measurements using absorption in the well known Hartley band (200 – 310 nm) at 254 nm. Since $O_2(^1\Delta_g)$ was also present, concentration measurements by using off-axis ICOS looking at the (1,0) band of the $b^1\Sigma_g^+$ - $a^1\Delta_g$ Noxon system [5]. were also performed. To ensure that the effect of O_3 could be isolated, an uncoated metal filter was placed in the flow to remove O_2 $(^1\Delta_g)$.

The results of this work indicated that O_3 concentrations as low as 1% could yield kinetic lifted flame speed enhancement of several percent. This work provided some of the first experimental evidence of the individual enhancement effects of O_3 produced by plasma.

References

1. Ombrello, T, Qin, X., Ju, Y., Gutsol, A., Fridman, A. and Carter, C., *Combustion Enhancement via Stabilized Piecewise Non-equilibrium Gliding Arc Plasma Discharge*, AIAA Journal, Vol. 44, No. 1, 2006, pp. 142-150.
2. Ombrello, T., Ju, Y., and Fridman, A., *Kinetic Ignition Enhancement of Diffusion Flames by Non-Equilibrium Magnetic Gliding Arc Plasma*, AIAA Journal, accepted, in press.

3. Ombrello T. and Ju, Y., *Kinetic Ignition Enhancement of H_2 versus Fuel-Blended Air Diffusion Flames Using Non-Equilibrium Plasma*, IEEE Transactions on Plasma Science, submitted, in review.
4. Gluckstein, M.E., Morrison, R.B., and Khammash, T.B., *Combustion With Ozone-Modification of Flame Speeds and C_2 Hydrocarbon-Air Mixtures*, Reports Control No. OSR-TN-227, 1 August 1955.
5. Williams, S., Gupta, M., Owano, T., Baer, D.S., O'Keefe, A., Yarkony, D.R. and Matsika, S., *Quantitative Detection of Singlet O_2 by Cavity-Enhanced Absorption*, Optical Letters, Vol. 29, No. 10, 2004, pp. 1066-1068.

***Timothy Ombrello** was born in 1980 in New York. He received his Bachelor of Engineering in Mechanical Engineering from The Cooper Union for the Advancement of Science and Art in 2003 and is currently a doctoral candidate in the Department of Mechanical and Aerospace Engineering at Princeton University. His research interests include the development and understanding of plasma assisted combustion systems through simplified experimental platforms and optical diagnostic techniques with numerical simulations for validation.*

Liftoff and Blowoff of Nonpremixed Laminar Jet Flames in Electric Fields

S. H. Won, S. K. Ryu, *M*. K. Kim, , S. H. Chung
School of Mechanical and Aerospace Engineering, Seoul National University, Seoul , Korea

M. S. Cha
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The stabilization characteristics of liftoff and blowoff in nonpremixed laminar jet flames in a coflow have been investigated experimentally for propane fuel by applying AC and DC electric fields to the fuel nozzle with a single-electrode configuration. The liftoff and blowoff velocities have been measured by varying the applied voltage and frequency of AC and the voltage and the polarity of DC.

The results in Fig. 1 showed that the AC electric fields extended the stabilization regime of nozzle-attached flame in terms of jet velocity. As the applied voltage of AC increased, the nozzle-attached flame was maintained even over the blowout velocity without having electric fields. In such a case, a blowoff occurred directly without experiencing a lifted flame. While for the DC cases, the influence on liftoff was minimal. There existed three different regimes depending on the applied AC voltage. In the low voltage regime, the nozzle-detachment velocity of liftoff or blowoff increased linearly with the applied voltage, while nonlinearly with the AC frequency. In the intermediate voltage regime, the detachment velocity decreased with the applied voltage and reasonably independent of the AC frequency. At the high voltage regime, the detachment was significantly influenced by the generation of streamers. To further understand the effect of electric fields on the nozzle-attached flame prior to the detachment from the nozzle, PLIF images for OH radicals were taken to visualize the variation of flame structure as varying the applied voltage and frequency of AC electric fields.

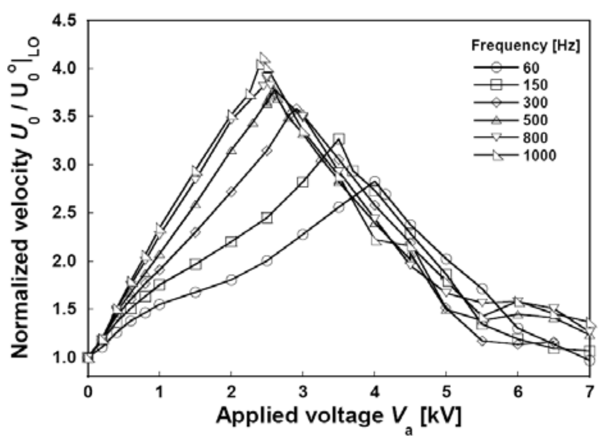

Fig.1. Normalized detachment velocity with AC voltage at various frequencies

As shown in Fig. 2, as increasing the applied voltage in low voltage regime, the flame size became smaller, meaning that the electric fields enhanced the overall diffusion transport. On the other hand, by increasing the AC frequency, the flame edge moved slightly toward the nozzle tip. However, to elucidate the detailed interaction mechanism between the reacting flow and electric fields, more intensive study will be needed in the future.

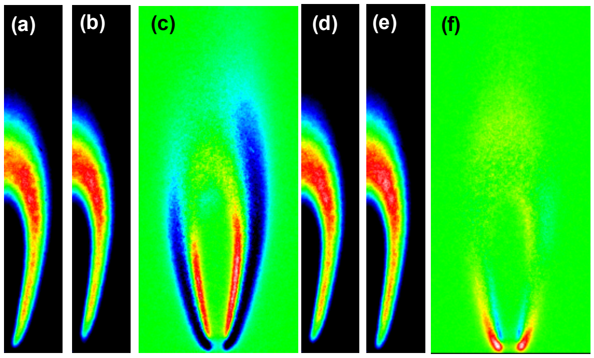

Fig.2. OH PLIF images of nozzle attached flame for V_a = 0, (b) 4 kV, (c) subtraction image between 4 kV and 0 kV at f = 60 Hz for U_o = 7 m/s, and (d) f = 60, (e) 500 Hz and (f) subtraction image between 500 Hz and 60 Hz at V_a = 3 kV for U_o = 7 m/s

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Subcritical Streamer Microwave Discharge in Reverse Vortex Combustion Chamber

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The present investigations are devoted to analysis of the combination possibility of two innovation technologies in one device: application of initiated streamer microwave (MW) discharge for inflammation, and combustion stabilization of fuel mixtures in a reverse-vortex combustion chamber of "Tornado" type. The results of pulsed subcritical streamer MW discharge in quasi-optical wave beam experimental investigations at atmospheric pressure in the model combustion chamber "Tornado" with dielectric walls have been presented. The surface MW streamer discharge formation possibility in new conditions has been confirmed, in particular, on dielectric walls of the cylindrical chamber. A scheme of initiated streamer MW discharge realization, at which discharge development takes place in a volume of the combustion chamber, has been proposed. It has been shown that the streamer subcritical MW discharge can be applied for ignition of fuel mixtures in axial area of the "Tornado" type combustion chamber.

Experimental tests have been carried out in a stand which scheme is represented in Fig.1.

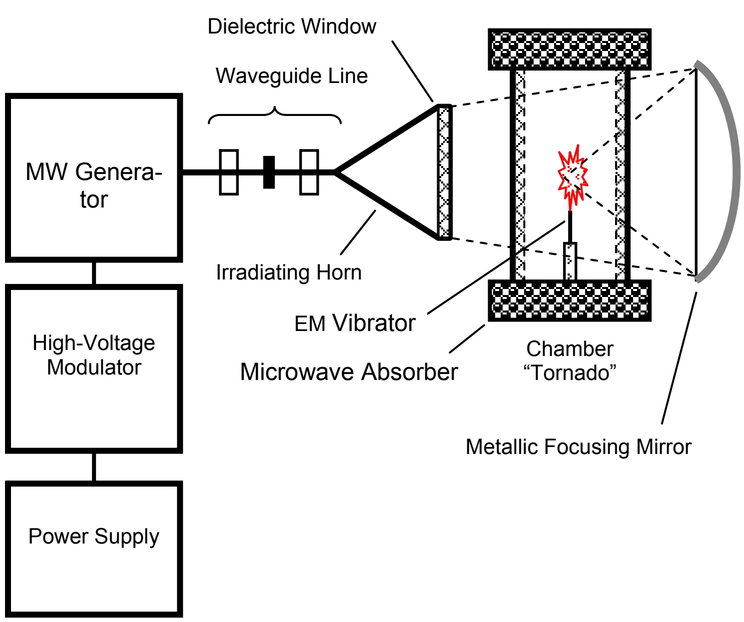
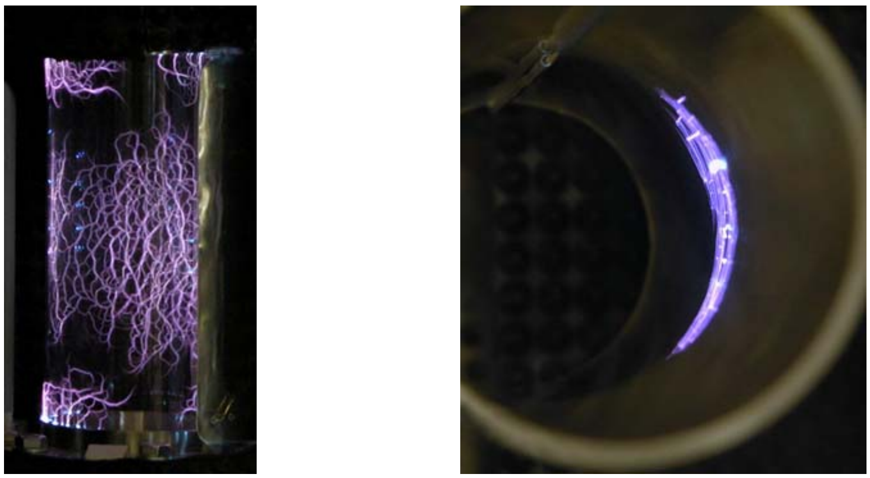


Fig.1. A scheme of the experimental set up for investigations of the streamer MW discharge in the "Tornado" chamber

The output power of the magnetron type pulse MW radiation source was $P = 2\cdot10^6$ W, wavelength $\lambda = 8.9$ cm, and pulse duration – 40 μs. An aperture of a radiating rectangular horn with sizes 90×72 mm was closed by a dielectric radiotransparent window. The vector E_0 in the outlet horn's cross section at that was oriented along its larger size. MW energy flux density in this cross section can be estimated as $3\cdot10^4$ W/cm^2, and E_0 value as $5\cdot10^3$ V/cm. The cylindrical part of the "Tornado" chamber is made of a quartz tube with internal diameter of 73 mm with a thickness of walls 2 mm. The MW discharge initiator represented an electromagnetic (EM) vibrator – the rectilinear section of a thin metallic wire of 0.2 mm diameter and ~ 40 mm length. Experiments have been carried out both with a metallic mirror focusing a radiation and without it.

A photography of MW discharge from one side of the "Tornado" chamber one can see in Fig.2a.



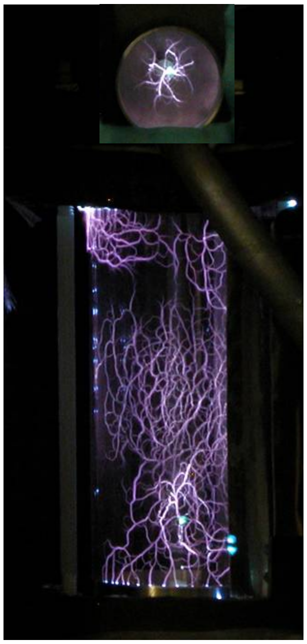
a) a side view *b) a view from above*

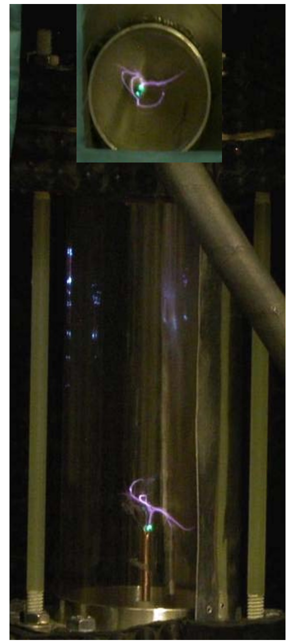
Fig.2. An appearance of the discharge at EM vibrator's position on an internal surface of the chamber

The experimental results have shown that the MW discharge separation from the surface takes place in the conditions of the experiments only if the level of the field is smaller by two times than those of the critical one E_{cr}. This condition was not achieved in the initial scheme. However, we confirmed a phenomenon of the streamer subcritical MW discharge realization on a curvilinear surface of a dielectric material.

We have changed the scheme of location and fixing of the initiator. EM vibrator in new series of experiments was located at the axis of the chamber and was fixed on an end of a dielectric tube near the face of the chamber, in the area of the standard branch pipe. Changes brought in the design have lead to desired result: the new scheme has allowed to localize the discharge on the chamber's axis.

In Fig.3a one can see an appearance of the initiated subcritical streamer MW discharge at pulse power of the radiation source $P = 3\cdot10^5$ W and the field amplitude $E_0 = 2.5$ kV/cm in the place of EM vibrator's location. In Fig.6b one can see the deeply subcritical MW discharge at $P = 5\cdot10^4$ W and $E_0 = 1$ kV/cm. In inserts in the upper parts of the photos, the discharge appearance is represented from the chamber's face. Channels of the subcritical discharge in the first case fill a considerable volume of the chamber, but in the second case the deeply subcritical MW discharge is attached to the initiator.

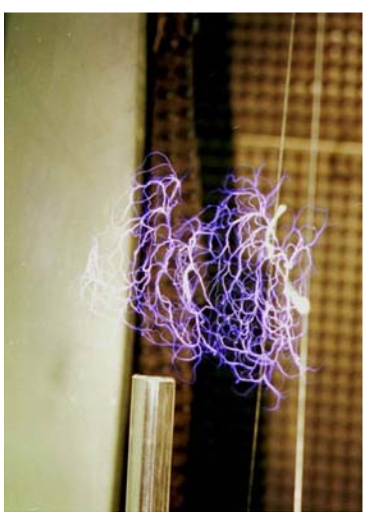




a) subcritical MW discharge *b) deeply subcritical MW discharge*

Fig.3. Discharge appearance at EM vibrator's location on the axis of the chamber

In Fig.3a one can see an appearance of the initiated subcritical streamer MW discharge at pulse power of the radiation source $P = 3{\cdot}10^5$ W and the field amplitude $E_0 = 2.5$ kV/cm in the place of EM vibrator's location. In Fig.3b one can see the deeply subcritical MW discharge at $P = 5{\cdot}10^4$ W and $E_0 = 1$ kV/cm. In inserts in the upper parts of the photos, the discharge appearance is represented from the chamber's face. Channels of the subcritical discharge in the first case fill a considerable volume of the chamber, but in the second case the deeply subcritical MW discharge is attached to the initiator.



a)

b)

Fig.4. A typical structure of the streamer subcritical discharge (a) and a combustion of a fuel gas mixture initiated by it (b)

Investigations have shown that the streamer subcritical MW discharge with a volumetrically developed structure can be applied for a volumetric ignition, for example, of a lean propane-air mixture, see Fig.4. An antenna that radiates the MW wave is located to the left in these photos (it is not shown in Fig.4), and the wire vibrator-initiator fixed by Capron threads is located to the right.

The main result of our work consists in development of the physical and technological principles of lean flammable mixture volumetric ignition system at the streamer subcritical microwave discharge application in the "Tornado" type combustion chamber. We have proven appropriateness of the idea and efficiency of two innovation technologies combination .

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Development and Preliminary Test Results of the Supersonic Plasma Igniter

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Preliminary test results of a combined cycle plasma torch in a short-duration blowdown wind tunnel [1] showed an opportunity to reduce dramatically electrical power of the plasma igniter by small addition of the gaseous hydrocarbon fuel into the arc chamber. That initiated the second stage of the igniter development for tests on a full-scale supersonic combustor model.

The main objectives of the second stage were as follows:

- Improve the igniter design to provide almost independent operation of the plasma and fuel modules;
- Widen the plasma generation module power range while operating with the supersonic exit velocity;
- Optimize and widen the fuel flow rate;
- Integrate igniter into the existing combustor design;
- Develop a power supply with regulative output and remote control of the main parameters.

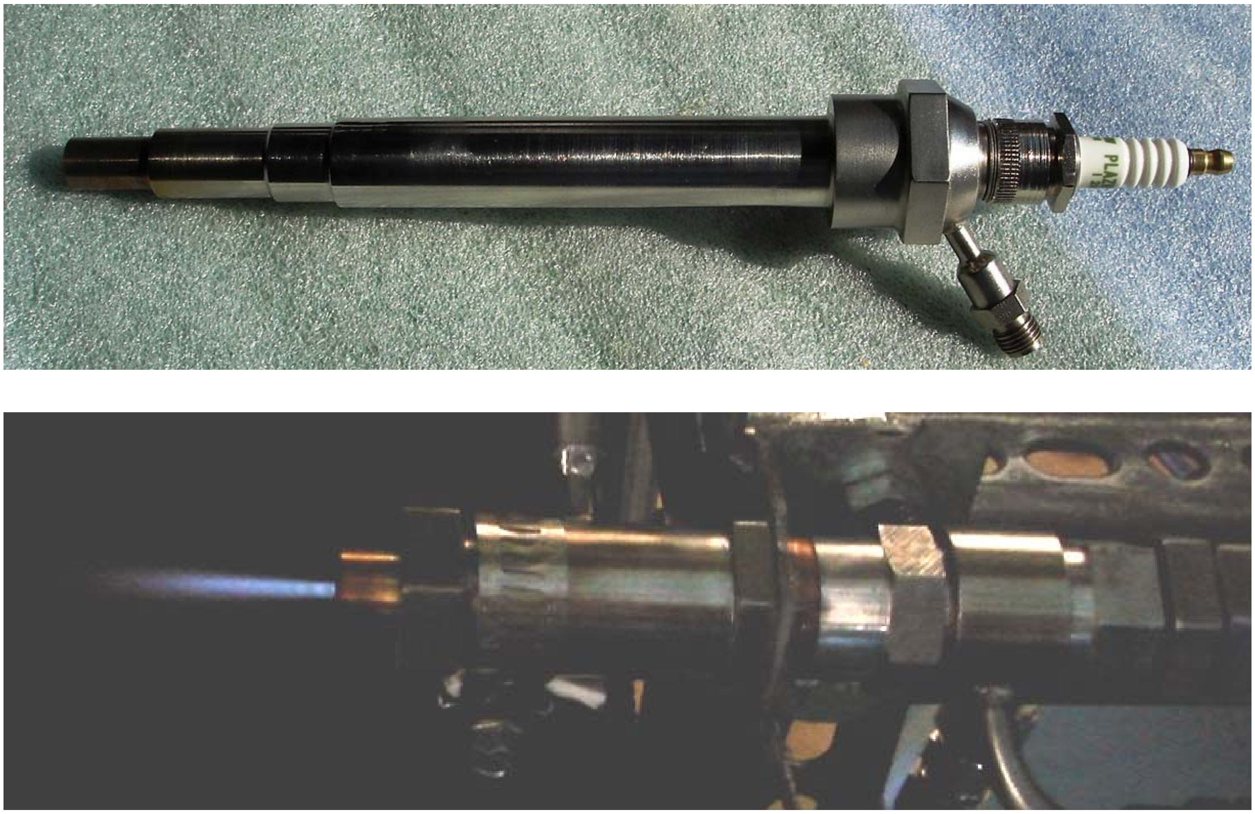

Fig.1. Combined cycle plasma torch.

As a result of almost one year of intensive prototyping and tests, a new igniter version has been developed (see Fig.1). It provides stable plasma formation within the air flow rate by 3.2 g/s, fuel flow rate (methane) 0.2 g/s and electrical power by 1.7 kW. Supersonic plum can be observed from the air flow 1.5-2.0 g/s for the pressure differential over 2 bar for electrical arc power 650-800W. Volt-current characteristics in Fig.2 below show the igniter operation with fuel feeding. Therefore wide ranges of operating parameters allow application of the developed igniter for a variety of combustors, including flame control modes of different fuels from gaseous to liquid ones.

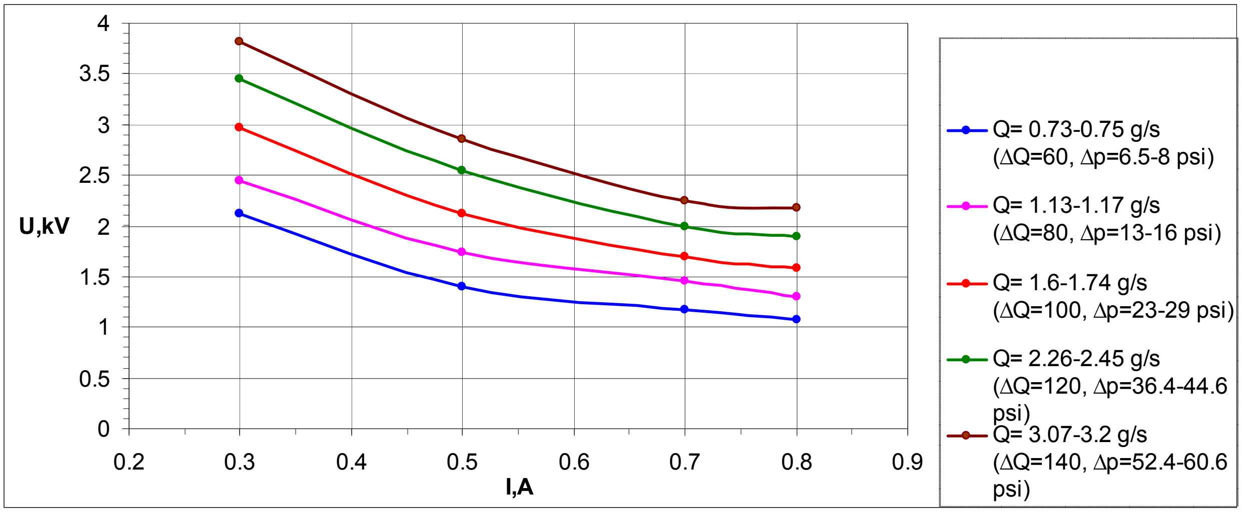

Fig.2. Volt-current characteristics

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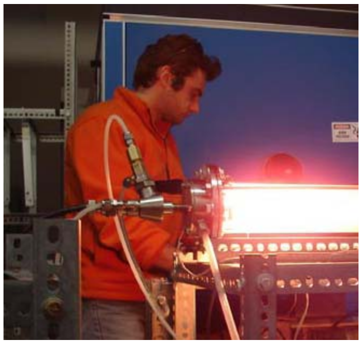

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Air-propane Mixture Ionization for Optimization of Ignition at Application of Gas Discharges

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The ionization process is a bottleneck at the plasma creation in electronegative gases of air-hydrocarbon mixtures. The clarification of lowest values of the ionization coefficient at given pressure and corresponding optimization of the mixture parameters in principle allows to decrease energy put to ignition and to clarify optimal characteristics necessary for combustion activation in combustors. Since the mixture composition in real conditions changes locally and can vary from lean to rich values, it is necessary to have information about mixture breakdown fields and ionization in such mixtures in a wide range of the mixture composition. The work is devoted to this analysis in propane-air mixture for which we investigated kinetics of electrons and negative ions at the initial stage of this mixture breakdown and calculated the Boltzmann equation in order to obtain the necessary rate constants of electron-molecule processes.

At analysis we consider pressure range p > 15-20 Topp. The concentration of electrons N_e is determined by a number processes: direct and background ionization of molecules O_2, N_2 and propane by slow and fast (background) electrons *e, e'*

$$e+O_2 \rightarrow O_2^+ + 2e \;, \quad e+N_2 \rightarrow N_2^+ + 2e \;, \quad e+C_3H_8 \rightarrow C_3H_8{}^+ + 2e \qquad (1.a)$$

$$e'+O_2 \rightarrow O_2^+ + e' + e \;; \quad e'+N_2 \rightarrow N_2^+ + e' + e \;; \quad e'+C_3H_8 \rightarrow C_3H_8{}^+ + e' + e \qquad (1.b)$$

with creation of ions O_2^+, N_2^+ and $C_3H_8^+$. We considered the following attachment and detachment processes of electrons to O_2 molecules with creation and elimination of negative ions O^-, O_2^- and O_3^- **:**

$$e+O_2 \rightarrow O^- + O \;, \qquad (2)$$

$$O^- + M \rightarrow e + O + M - 1{,}46\, eV \;, \qquad (3a)$$

$$O^- + N_2 \rightarrow e + N_2O + 0{,}23\; eV \;. \qquad (3b)$$

$$O_2^- + M \rightarrow e + O_2 + M \;. \qquad (3c)$$

$$O^- + C_nH_{2n+2} \xrightarrow{k_b} \begin{cases} \xrightarrow{\kappa k_b} OH^- + C_nH_{2n+1} \\ \xrightarrow{(1-\kappa)k_b} H_2O + C_nH_{2n} + e \end{cases} \qquad (3d)$$

rate constant of electron detachment in this process in case of propane is $k_{det4}= 6\times10^{-10}$ cm^3/s (Arnold S.T. et.al, 1998).

$$O^- + O_2 \rightarrow O_2^- + O - 1{,}02\,eV \qquad (4)$$

$$O^- + O_2 + O_2 \rightarrow O_3^- + O_2 \qquad (5)$$

Rate constants of ionization and attachment in propane – air mixture and other kinetic coefficients at constant electric field were obtained on a basis of Boltzmann equation solution with electron- propane cross sections from (Hayashi M.,1985).

A system of equations for electrons N_e and negative ions O^- and O_2^- at moderate and high pressures and moderate temperatures leads to the following solution for electron concentration

$$N_e = \frac{a_5 \cdot Q}{a_1 \cdot a_5 + (a_2 + a_6) \cdot a_4} \cdot \left(\exp(\nu_{eff} t) - 1\right) \qquad (6)$$

where n_{eff} is effective ionization frequency, which can be obtained at solution of the system of equations;

$$a_1 = \nu_i - \nu_a \;;\quad a_2 = \nu_{\det 1} + \nu_{\det 2} + \nu_{\det 4} \;;\quad a_3 = \nu_{\det 3} \;;\quad a_6 = \nu_{ch\,1} \;;\quad a_4 = \nu_a \;;$$

$$a_5 = \nu_{\det 1} + \nu_{\det 2} + \nu_{\det 4} + \nu_{ch\,1} + \nu_{ch\,2} \;.$$

A denominator in (6) has to be positive, or the following condition has to be satisfied:

$$\nu_i \cdot (\nu_{\det 1} + \nu_{\det 2} + \nu_{\det 4} + \nu_{ch2} + \nu_{ch1}) - \nu_a \cdot \nu_{ch2} > 0 \;. \qquad (7)$$

At C_3H_8 > 2% in air it has the form

$$k_i > k_a \cdot \frac{k_{ch2}}{k_{\det 4}} \cdot \frac{\eta_{O_2}^3}{\eta_{C_3H_8}} \cdot N \;,$$

where h_{O2} and h_{C3H8} – portions of oxygen and propane molecules in the mixture and, N – is the total number density of molecules in it. The threshold E/N at which the condition (7) is satisfied determines the initial breakdown conditions. In Table 1 we demonstrate its values for propane-air mixture at its various compositions.

Table 1. Breakdown values of propane- air mixture, E/N, $\times10^{-17}$ $V\cdot cm^2$,

C_3H_8	0%	2%	4%	10%
T=300 K	91	50	37	27

Our analysis has shown that breakdown conditions in pure air are in agreement with known breakdown field (~25 kV/cm) at normal atmospheric conditions. They are defined by ionization of molecules and detachment of electrons from oxygen negative ions. In the case of propane-air mixture, the process of detachment (3d) decreases effective breakdown fields even more and facilitates electric energy put in to the flammable mixture.

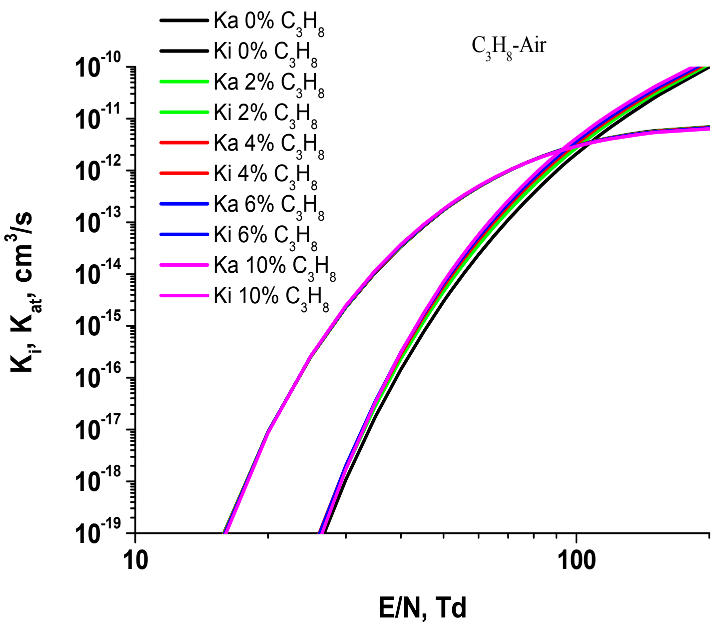

Fig.1. Ionization and attachment rate constants dependences via E/N in propane-air mixture

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Plasma-Assisted Ignition and Combustion of Hydrocarbon Fuel in High-Speed Airflow by HF Streamer Discharge

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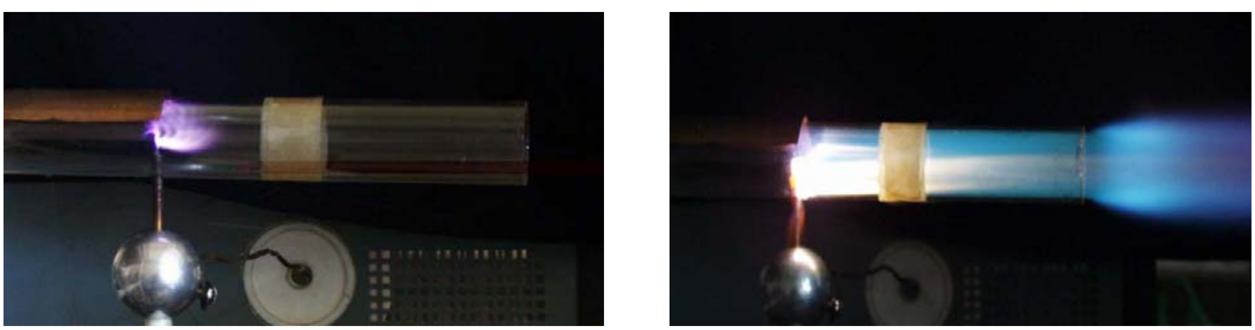
Non-premixed plasma-assisted combustion (PAC) of hydrocarbon fuel in high-speed airflow was studied in our previous works [1-3]. This work is continuation of the previous ones. New experimental results on *non-premixed PAC* in high-speed airflow are considered in this work. Experimental study of internal PAC is carried out in the different experimental setups. HF streamer discharge (mean power < 2 kW) is used for airflow pre-heating and fuel-airflow radical generation. Optical spectroscopy, FTIR method, chemical analysis, power balance (calorimetric) method are used to study plasma and radical generation in PAC zone. Experimental results on internal PAC are considered and discussed in this work. The following main experimental results are obtained in this work:

1. It is revealed that HF streamer propagation velocity is about ~ 10^4 m/c and higher. Its value is depended on electric field of HF pulse namely. This velocity is much higher than a typical velocity of gas flow (less than 1000m/s) in a combustor.
2. The final gas flow composition behind PAC zone is measured by IR spectrometer, chromatograph and chemical gas analyzer. The concentrations of the final species are measured behind PAC zone at different operation modes of HF plasma generator.
3. High PAC completeness of lean mixtures (*ER = 2-4*) is obtained in high speed airflow.
4. Detail optical spectra are recorded in different cross sections of the PAC zone at different operation modes of plasma generator. These spectra are processed and analyzed.
5. HF streamer is a non-equilibrium plasma formation created by capacity HF discharge in high-speed airflow. This plasma formation can create radicals and excited particles in fuel-airflow mixture effectively.



a) b)

Fig.1. HF streamer discharge in high-speed airflow (a) and combustion of non-premixed propane in high-speed airflow assisted by HF streamer discharge (b): M=0,6; p_{st}=1 Bar, T_0~ 300K, F_{HF}=13,6 MHz, modulation frequency F_i~ 100Hz,Ti~ 6ms

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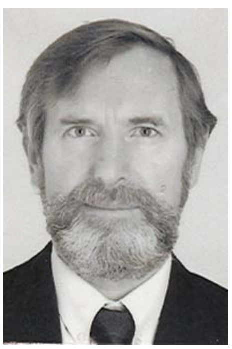

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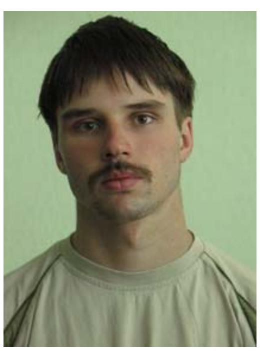

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Atmospheric Pressure Reverse Vortex Microwave Plasma Generator

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Modern industry at intensifications of technological processes often applies low temperature plasma as a working body. There are different methods of a plasma generation. Among them microwave (MW) plasma generators occupy a special place due to the unique features of MW discharges in gases. To the well known advantages of MW plasma generators, one can attribute the absence of plasma and processing material contamination by products of erosion at high efficiency of electromagnetic energy delivery (MW energy put into plasma efficiency can reach).

A relatively new and prospective direction in the development of powerful plasma generators is a vortex-type plasma generator. Here we represent results of our recent investigations of the comparably new design of the atmospheric MW plasma generator of this type. The electrodynamic scheme of the plasma generator is presented in Fig.1.

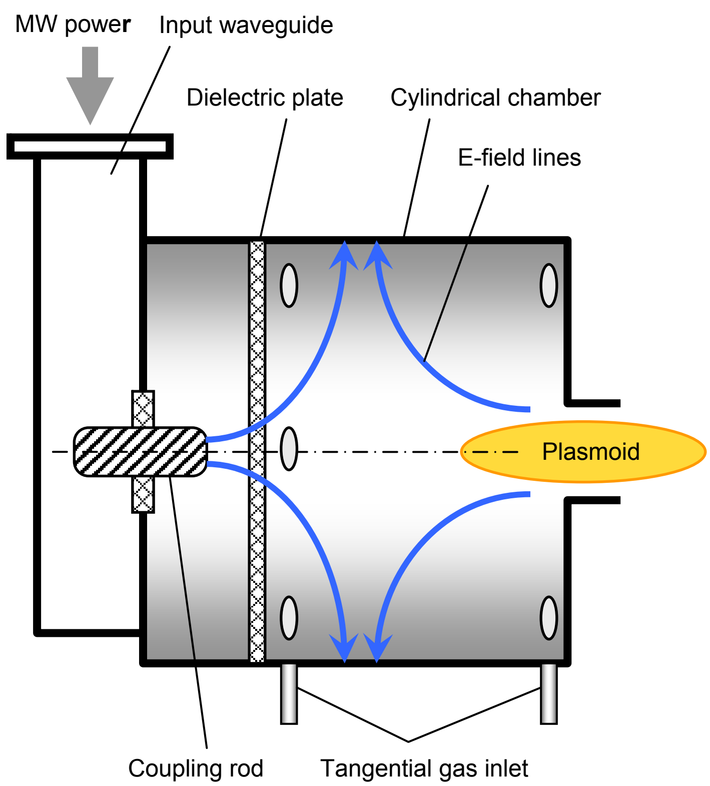

Fig.1. Electrodynamic scheme of the plasma generator

The plasma generator is fed by a magnetron of 1.5-2.5 kW power with a working frequency of 2.45 GHz through a standard waveguide WR340 (86x43 mm). Mw energy with a help of a coupling post (analogue of coaxial-to-waveguide transition unit) comes to a cylindrical waveguide excited at a wave E_{10} type. The force lines of electric field $\boldsymbol{E}$ in a chamber of the plasma generator are shown by blue color lines. A working gas vortex flow and so called recirculation zone (which coincides with the plasmoid position) is formed by a system of tubes of the gas line with the tangential inlet orifices in the chamber.

The whole line represents a well-matched line with negligible VSWR coefficient starting from a moment of the plasmoid formation, in which the plasmoid plays a role of a matched load. A principally important condition in such a design of the MW plasma generator consists in the alignment of the recirculation zone (it is the zone of low pressure) with an area of highest density of electromagnetic energy; which means that there is a maximum of the electric field in the right part of the chamber in a region of an outlet nozzle. In order to prevent a discharge initiation at the inlet to the chamber (to the left in the figure), we have separated the chamber into two parts by a dielectric plate. A small excess pressure is created with additional inlet from the gas line (it is not shown in the picture) in the left hand isolated part of the chamber.

Fig.2. An appearance of the plasma generator

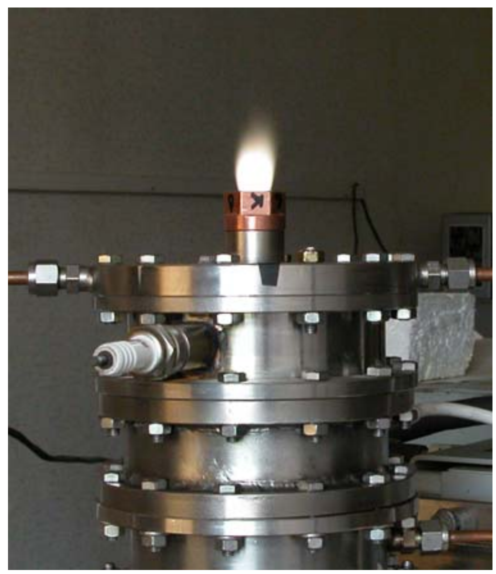

Fig.3. An appearance of the plasma torch (working gas is air)

Thus there are absent any quartz or ceramic tubes being in contact or in direct vicinity to the plasmoid in the developed design. The chamber does not require a water cooling in the investigated range of power 1.5-2.5 kW ; the outlet nozzle stays cold during the operation.

The appearance of the plasma generator is represented in a photo in the Fig.2, and an appearance of the plasma torch near the outlet nozzle is represented in Fig.3.

Our investigations have shown that a form of a flame is very stable in indicated above range of power at the working gas rates (of air and nitrogen) in an interval 0.5-2.0 liter/s. More than that, it became clear during the tests that considered plasma generator has a remarkable feature: we obtain as if a self-consistent device after choice of the plasma generator’s geometry and matching of the gas flows in the chamber.

Investigations of the considered plasma generator have been started. We continue following the optimization of its design and operation modes. However, even now one can state that the proposed version of the MW plasma generator differs advantageously from analogues by a set of exploitation characteristics, simplicity of the design and work stability.

This device is ready for application in such tasks, for example, as nitriding of steel and alloys surface and some other materials processing.

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Longitudinal Plasmoid in High-Speed Vortex Gas Flow Created by Capacity HF Discharge

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Plasma-shock wave interaction, plasma-acoustic wave interaction and plasma aerodynamics were studied in a number of works (for example, [1]). Unfortunately vortex structure and its dynamics in non-equilibrium weakly ionised plasma are studied insufficiently (or non-detail) today. This task is very important for the possible application in aviation and plasma-assisted combustion [2-7].

The effects of non-equilibrium energy input on gas dynamics should be best seen at low pressure. In the present work, the interaction of longitudinal HF discharge with high-speed swirling flow (V_t~100m/s) in a tube is under consideration (see fig.1).

The airflow, pressure and velocity distributions are measured. It is revealed that the discharge ignition in a channel leads to significant decrease of the radial pressure drop in the vortex.

As for the discharge itself, rotational and vibrational temperatures are measured in different tube cross-sections via optical spectroscopy method. The increase of T_v/T_r is obtained at the ends of HF plasmoid.

The results obtained are compared with preceding results on the DC discharge in the swirling flow in a tube [8] and calculation results [9].

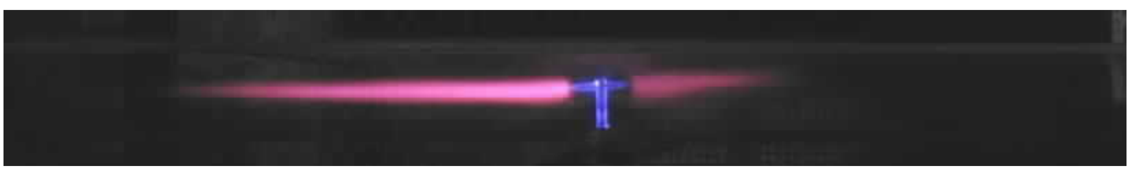

Fig.1. Longitudinal HF plasmoid dynamics at the different mass flow rates Q. Vortex airflow, P_{st}~40 Torr, N_{HF}~800W

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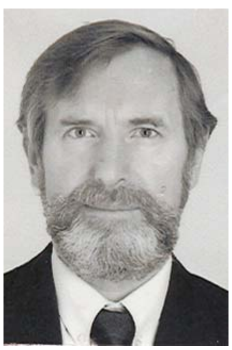

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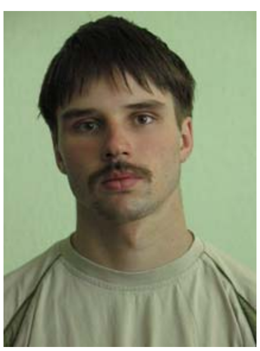

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Experimental Investigations of the Hybrid Plasma Torch with Reverse Vortex Stabilization

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One of the most widespread areas of plasma technology is waste processing. Plasma as a heat-transfer agent with high concentration of energy account for its wide application opportunities.

Arc (DC) and radio-frequency (RF) induction electrical discharges are used in the in the industry for generation of plasma.

Arc plasma torch do not provide necessary parameters of plasma for technological processes. DC torch's biggest problem is plasma jet contamination by material of electrode erosion and the limited life of continuous work.

Unique technical characteristics of RF plasma torch in comparison with arc plasma torch are:

- Plasma generation in a large volume;
- Cleanness of plasma due to no-electrodes;
- Simplicity of a design;
- Possibility of wide change of a plasma velocity;
- Simplicity of in-feeding into plasma;
- Long time of material staying in plasma jet;
- Long life;
- Reliability in operation;
- Workability various gases, including aggressive;
- Possibilities of power scaling up to 10 MW.

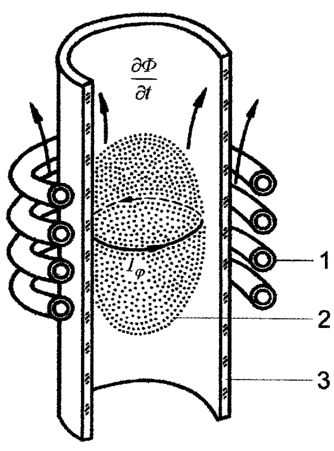

Fig.1. Plasma induction heating
1 – inductor, 2 – plasma, 3 – quartz tube

Radio-frequency induction plasma torch is intended for generation of non-electrode pure plasma in an atmosphere of various gases: air, argon, nitrogen and other. Heating of plasma gas inside the RF plasma torch is provided by the energy of alternated electromagnetic field (see Fig. 1). Plasma torch consists of the following basic elements: metal water-cooling sections (fingers); quarts tube; body-corpus and gas former (see Fig. 2).

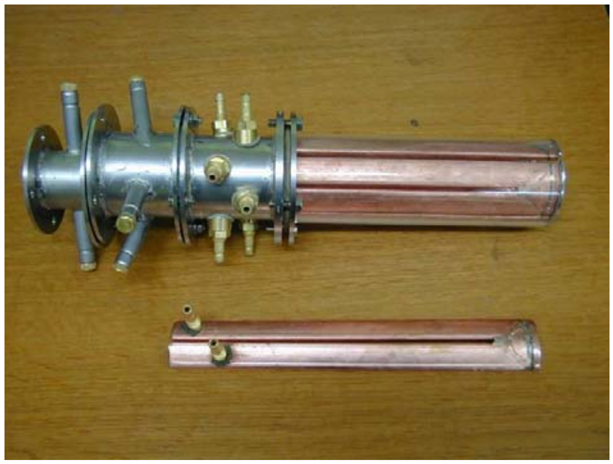

Fig.2. Metal water cooling RF plasma torch
(One section of the metal water-cooling chamber is presented separately)

Reverse vortex RF plasma torch has the high efficiency of plasma energy. Therefore reverse vortex hybrid plasma torch has been chosen for experimental studies [2].

Reverse vortex hybrid plasma torch is a combination RF plasma torch and arc plasma torch. Schematically and visually hybrid plasma torch is presented on Figs. 3 and 4.

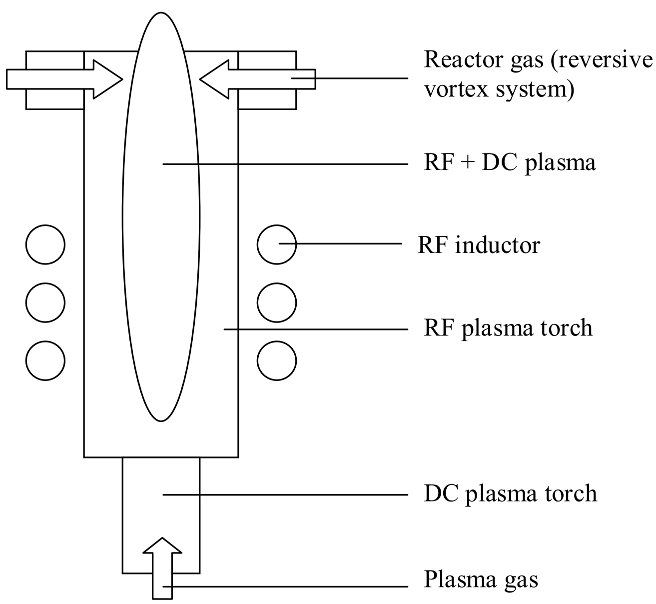

Fig. 3. Layout of the hybrid (RF + DC) installation

Fig.4. Hybrid (RF+DC) plasma torch (assembled)

Technical parameters of hybrid installation are resulted in Table 1.

Table 1. Adjectives of the experimental setup

Parameter	Meaning
Working frequency of the tube generator	5.28 MHz
Power of the RF plasma torch	15…25 kW
Power of the Arc plasma torch	10…15 kW
Weight-average temperature at the outlet cross-section of the plasma torch	5500 K
Type of a plasma gas	Air, Argon, Nitrogen
Gas flow rate	1…3 g/s

There are some procedures of ignition of RF plasma. It has been found experimentally that the arc plasma torch is the simplest embodiment for RF plasma ignition. Consequently arc plasma torch is used for ionization of gas-discharge area (see Fig. 5). Also arc plasma torch is used for preliminary waste heating also. For air arc plasma, the thermochemical hafnium electrode was installed. For argon and nitrogen arc plasma, the lanthanum tungsten electrode was installed.

In the issue of realized prime experiments, next hybrid torch properties and conditions have been studied:

1. Parallel start-up of DC and RF plasma torches.
2. Stability of the RF + DC discharge at the expense of gas flow effect.
3. Durability of the RF + DC discharge at the expense of power effect.
4. Maximum available gas flow at the expense of output RF torch diameter.
5. Durability of the RF + DC discharge at the expense of reverse gas both for arc torch swirler, and for RF torch gas former.

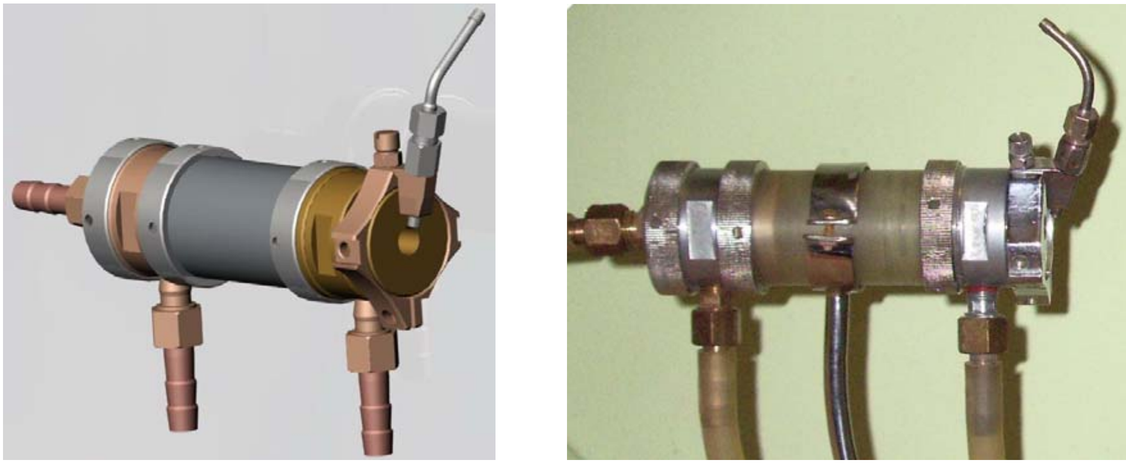

Fig.5. Arc plasma torch: 3D model and photo

As a result, it was possible to achieve total gas flow through hybrid torch equal 3 g/s in a mix plasma gas. Namely, gas flow rate through RF torch was 1.5 g/s and gas flow rate through DC torch was 2 g/s.

Ignition modes of hybrid torch were realized on next step. But the main goal of these experiments was studying of stability of the RF + DC discharge for pure air and nitrogen plasma gas under the stipulation that total gas flow was equal 3 g/s (it is maximum allowed gas flow received in the previous experiments).

It was not possible to ignite the discharge on pure air or nitrogen. Therefore plasma ignition occurred on argon, and then carried out the connection and transition to pure air or nitrogen plasma gas. Breakdowns between coils of inductor arose in transition on air or nitrogen regularly. Transient processes are the primary cause of these breakdowns. So gas change promotes variation of conductivity. It also causes an overvoltage. As positive result, inductor has been isolated by means of a protective cover.

Summary results are presented in Table 2. Visualizations of reversive vortex hybrid plasma torch operating modes in various atmospheres are presented on Figs. 6-8.

Table 2. Experimental data of hybrid torch investigations

Gas	**Parameters and modes of RF plasma torch**				**Parameters and modes of DC plasma torch**			
	U_a, kV	I_a, A	P_{RF}, kW	G_{RF}, g/s	U, V	I, A	P_{DC}, kW	G_{DC}, g/s
Argon	6.5	5.5	16	0.4-1.5	140	80	11	1.6-2
Air	6.5	5.5	16	0.8-1.5	100	100	10	1.2-1.5
Nitrogen	7..5	7	25	0.4-1.5	140-175	80-100	14	0.5-1

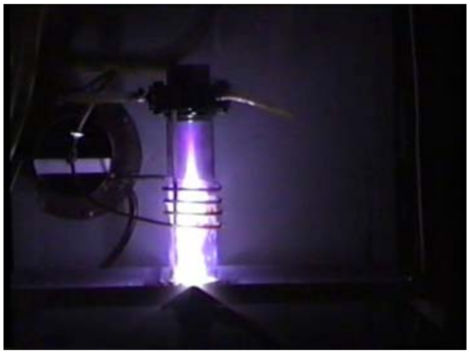

Fig. 6. Argon combined operation mode of hybrid (DC + RF) plasma torch

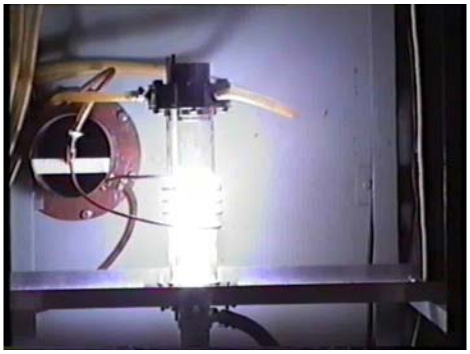

Fig. 7. Air combined operation mode of hybrid (DC + RF) plasma torch

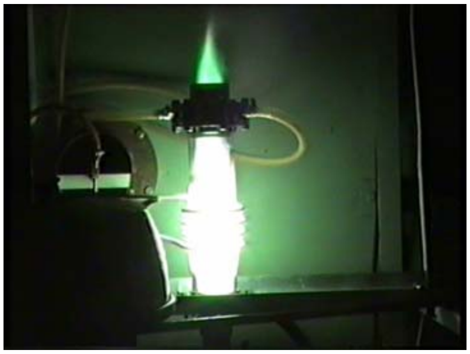

Fig. 8. Nitrogen combined operation mode of hybrid (DC + RF) plasma torches

Conclusions

1. Positive effect of hybrid (DC + RF) plasma torch combined operation mode in an atmosphere of various gases has been achieved.
2. Maximum gas flow through hybrid torch was equal 3 g/s. This rate has been defined experimentally.
3. Now there is a work on by designing reverse vortex hybrid (DC + RF) plasma torch with copper water-cooling chamber. In further is planned to increase power of hybrid plasma torch.

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Calculation of the Main Parameters of Inductively Coupled Plasma Torches for Technological Applications

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The features of plasma in RF ICP torches such as a high purity due to the absence of electrode and large volumes of plasma have resulted in a wide range of applications. Main technologies based on RF ICP torch application are the following: powder spheroidization, synthesis of ultra-fine powder, plasmachemical technologies, material treatment at reduced pressures etc.

Basic parameters in a RF plasma torch influencing plasma technological processes are temperature, enthalpy and velocity of plasma. The factors influencing these plasma parameters are gas type, plasma torch geometry, gas flow rate, plasma power and frequency value. Experimental determination of these plasma parameters is a problem. Therefore the calculation of plasma parameters in RF ICP torch for different plasma technologies is one of the alternatives.

Really the numerical modeling of plasma parameters in RF ICP torches is an effective method of investigation RF plasma torches. It is widely used to analyze the plasma processes, to explain the experimental facts, to acquire the new information on plasma, to select the optimal operating conditions of the RF torch. The history and modern status of the numerical modeling of plasma parameters in RF ICP torches are presented in works [1, 2].

At present work the numerical modeling of plasma parameters in RF ICP torches is carried out. The model is based on the following assumptions:

At present work the numerical modeling of plasma parameters in RF ICP torches is carried out. The model is based on the following assumptions:

- Gas flow is laminar, stationary, at atmospheric pressure.
- Plasma is axisymmetric.
- Plasma is optically thin.
- The thermodynamic equilibrium is present in the plasma.
- Viscous dissipation and pressure work in the energy equation, gravity force and displacement current are neglected.

The model of plasma involves the following equations:

- Equation of energy balance (the equation expresses energy conservation law)

$$\rho c_p \upsilon_z \frac{\partial T}{\partial z} + \rho c_p \upsilon_r \frac{\partial T}{\partial r} = \sigma E_\varphi^2 - u_{rad} - \frac{\partial}{\partial z}\left(-\lambda \frac{\partial T}{\partial z}\right) - \frac{1}{r}\frac{\partial}{\partial r}\left(-r\lambda \frac{\partial T}{\partial r}\right);$$

- Momentum transfer equations for axial, radial and tangential components of velocity (the equation expresses momentum conservation law)

$$\rho\left(\upsilon_z \frac{\partial \upsilon_z}{\partial z} + \upsilon_r \frac{\partial \upsilon_z}{\partial r}\right) = -\frac{\partial p}{\partial z} + \frac{\partial}{\partial z}\left(2\mu \frac{\partial \upsilon_z}{\partial z}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(\frac{\partial \upsilon_r}{\partial z} + \frac{\partial \upsilon_z}{\partial r}\right)\right] + F_z;$$

$$\rho\left(\upsilon_z \frac{\partial \upsilon_r}{\partial z} + \upsilon_r \frac{\partial \upsilon_r}{\partial r}\right) = -\frac{\partial p}{\partial r} + \frac{\partial}{\partial z}\left[\mu\left(\frac{\partial \upsilon_r}{\partial z} + \frac{\partial \upsilon_z}{\partial r}\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left(2r\mu \frac{\partial \upsilon_r}{\partial r}\right) - 2\mu \frac{\upsilon_r}{r^2} + \rho \frac{\upsilon_\phi^2}{r} + F_r;$$

$$\rho\left(\upsilon_z\frac{\partial\upsilon_\phi}{\partial z}+\upsilon_r\frac{\partial\upsilon_\phi}{\partial r}\right)=\frac{\partial}{\partial z}\left(\mu\frac{\partial\upsilon_\phi}{\partial z}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(\mu r\frac{\partial\upsilon_\phi}{\partial r}\right)-\frac{\upsilon_\phi}{r}\left(\rho\upsilon_r+\frac{\mu}{r}+\frac{\partial\mu}{\partial r}\right)+F_\phi\ ;$$

- Continuity equation (the equation expresses mass conservation law)

$$\frac{\partial}{\partial z}\left(\rho\upsilon_z\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\rho\upsilon_r\right)=0\ ;$$

- Equation of electromagnetic problem:

$$\frac{\partial^2\dot{E}_\phi}{\partial z^2}+\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\dot{E}_\phi}{\partial r}\right)-\left(\frac{1}{r^2}+\mathrm{j}\mu_0\omega\sigma\right)\dot{E}_\phi=0\ \cdot$$

In the equations resulted above following designations are used: r is mass density of plasma, kg/m^3; c_r is specific heat of plasma, J/(kg·K); υ_z, υ_r, υ_φ are axial, radial and tangential components of velocity, m/s; T is plasma temperature, K; σ is electrical conductivity, mho/m; E_φ is electric field intensity, V/m; u_{rad} is radiation power, W/m^3; λ is heat conductivity, W/(m·K); z, r, φ are coordinate of cylindrical system, m; p is pressure, Pa; μ is viscosity of plasma, kg/(m·s); F_z, F_r, F_φ are axial, radial and tangential components of the Lorentz force, N/m^3.

The system of non-linear differential equations including the two-dimensional equation of energy balance, momentum transfer equations, continuity equation and equation of electromagnetic problem was solved using the SIMPLER algorithm. This algorithm has been developed by S. Patankar [3].

The calculated ICP torch works at frequency of 5.28 MHz, plasma power is 20 kW, inner diameter of the torch is 54 mm, length of discharge chamber is 220 mm, plasma gas is air, and plasma gas flow rate is 1.5 g/s.

Experimentally plasma ignition occurred on argon, and then carried out transition to pure air plasma gas. Therefore two variants have been calculated. Namely argon and air plasma have been calculated. The thermo physical properties of argon and air plasma were taken from reference [4].

Distributions of following values were obtained: a temperature T, a plasma velocity υ_z, υ_r, υ_φ, a gas flow ψ, a pressure p and electromagnetic values. Integral power balances for the torch for different cases were compared.

The results of the calculations such as distributions of plasma temperature and gas flow in the torch are shown in Figs. 1 and 2.

Results show that the operating conditions (such as pressure, gas flow rate, coil position, nozzle) have considerable influence onto plasma parameters, in particular, a plasma flow. Changing the operating condition, it is possible to decrease plasma recirculation zone in a RF ICP torch.

Results of the calculation can be used for modeling of heat and mass transfer at waste processing in the plasma jet.

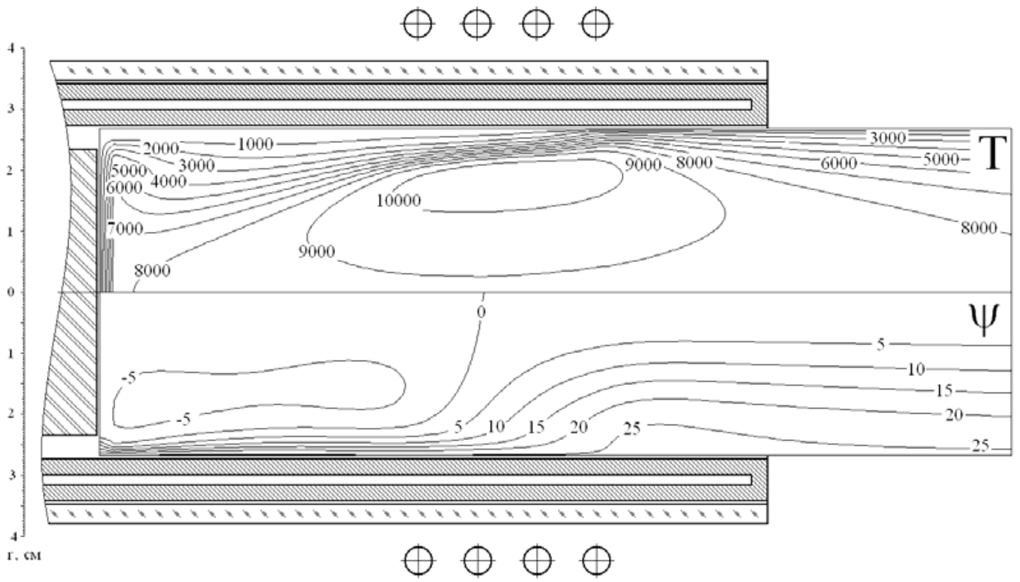

Fig.1. Distributions of argon plasma temperature T (K) and flow y (10^{-5} kg/s)

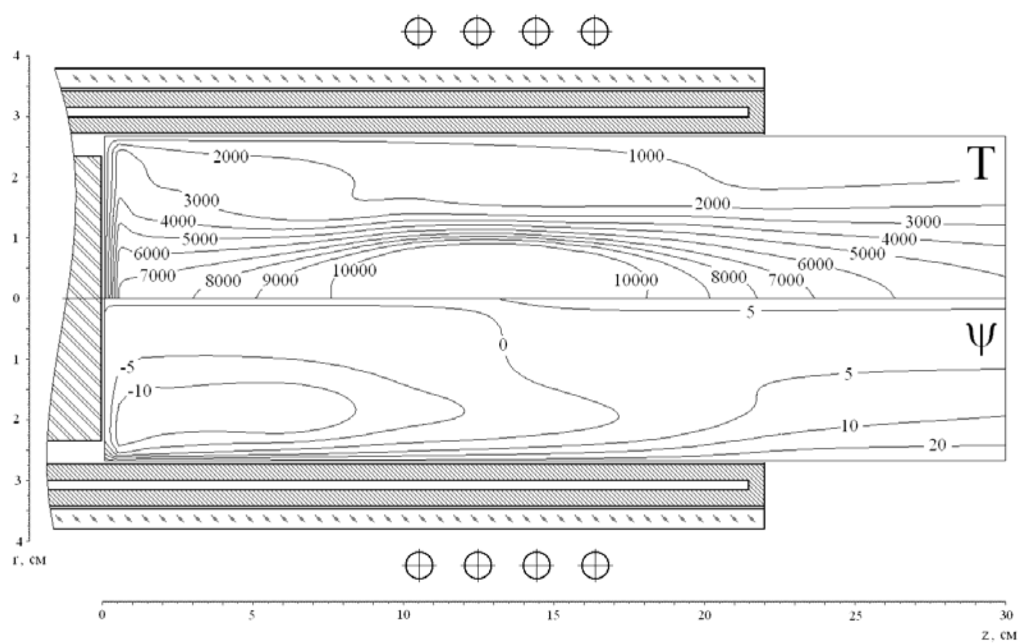

Fig. 2. Distributions of air plasma temperature T (K) and flow y (10^{-5} kg/s)

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Excitation of the Microwave Torch Discharge in a Single Conductor Line

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A waveguide-coaxial microwave module allowing a torch microwave discharge to be initiated in the open air at the end of a single-conductor transmission line is presented. The properties of the module and its possible applications for evaporating fine-grained refractory-material films on substrates are described.

There are a great variety of the ways enabling one to initiate microwave discharges, specifically, in waveguides under the effect of traveling or standing electromagnetic wave, in vacuum or gas-filled resonators. The microwave discharge is initiated [1-3] through the use of dielectric lens concentrators of fields, external ionizing radiation sources and free-electron beams. Another way of microwave discharge initiating can be found in [4].

A number of difficulties over visual and remote probing of the discharge process arise in the study into the properties of discharges in different gaseous media at different pressures in closed waveguide-and resonator-type systems. In this context, the goal of the present paper is to develop a setup, which allows one to obtain the discharge energy (under the microwave effect) outside the closed system, to optimize several assemblies of waveguide and coaxial lines of the whole arrangement, and to create the conditions for exciting the microwave discharge plasmoid at the end of the single-conductor line.

Description of the Microwave Setup Module and Experimental Results

In our case the microwave setup consists of magnetron oscillator (a commercial type of a continents-wave magnetron M-105 with an output power of 700 w at the 12-cm wavelength), resonator on a H_{10}-mode wave and coaxial line as it is shown in Fig. 1 [5].

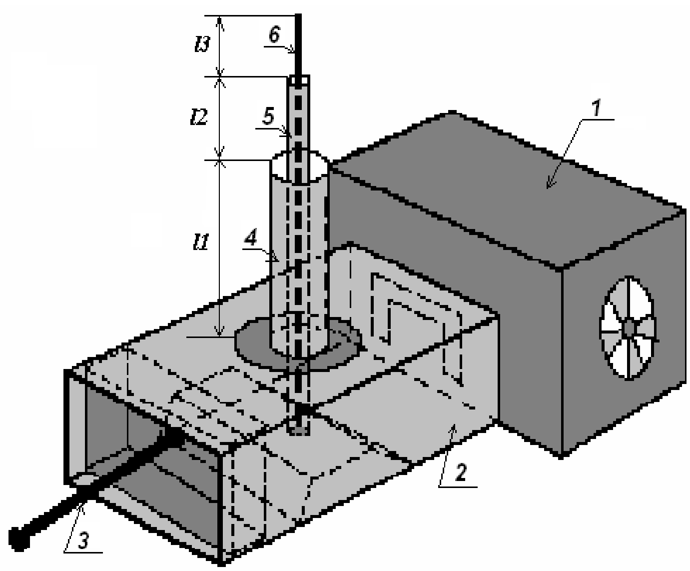

Fig.1. Microwave device consists of:
1) oscillator, 2) waveguide resonator with wave mode H_{10}, 3) plunger,
4) coaxial line with length 13 cm, 5) inner conductor, 6) Goubau line

The resonator, which is rectangular waveguide section 2 (90x45 mm2) abridged by moving shorting plunger 3, was excited through the U – aperture. The lower wide resonator wall is made in the form of truncated pyramid, which smoothly decreases the waveguide section along its narrow wall from 45 to 25 mm. This changes wave resistance and increases electric field density. The rectangular resonator is connected with coaxial line 4 (length *l1*) through the coupling window and inner conductor (length *l2*) of coaxial line goes into single-conductor Goubau line with the length *l3*.

In general the electrodynamics characteristics of the device in question were calculated in terms of its generalized scattering matrix according to the two-stage circuit. In the initial stage, the above arrangement was split into a set of simpler in homogeneities in conformity with the decomposition principle, and the solutions to the relevant scattering problem for each of these in homogeneities were found. In the second stage, the scattering matrix of the device as a whole was determined from the already found scattering matrices of these in homogeneities. The calculated characteristics of the waveguide assembly are presented in [5].

During the experiment the following refractory materials such as W, Ta, Mo, Ni, were utilized to produce a single-wire transmission (Goubau) line. Their melting temperatures were 3380^0C (for W), 3000^0C (T), 2626^0C (M_0), 1450^0C (Ni), respectively.

Fig. 2. The discharge initiated at the end portion of the single-wire Goubau line.

The photo of one of the standard discharges glowing at the end portion of the tungsten wire 0.4mm across and equal to three wavelengths is shown in Fig. 2. Visual observation of spherical plasmoid was possible with the help of light filters. In our case the discharge process filming was done with light filter “FS - 6” with glass thickness 1mm. The color of the discharge is dependent upon a particular conductor material. For copper it is reddish, for tungsten it is white.

Conclusions

The experimental results indicated that microwave discharge initiation in our system for different materials is primarily governed by the conductors melting temperature, i.e. the higher the temperature, the greater mw input power from the magnetron is required. Basically the discharge by its nature is of erosion type. Specifically, the material of the conductor sublimes into the atmosphere at a high temperature, i.e. it evaporates without passing through a liquid phase. For tungsten the evaporation temperature is about 5000^0C.

Developed microwave setup is easy in operation and it can be utilized in different technological applications.

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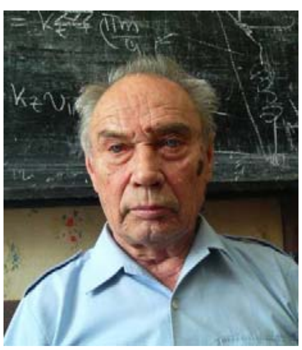

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Numerical Analysis of a Nanosecond Discharge Dynamics

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The problem of organization of the effective combustion regime in automotive engines is one of the actual tasks of modern mechanical engineering connected with the ecological problems of environmental protection from automotive exhaust gases. The problem solution is connected with the organization of stable a combustion process of lean mixtures in particular with the realization of lean ignition limits on the early stage of flame kernel formation. It is known that the flame propagation speed decreases with air/fuel ration increasing and the special organization of ignition process is needed to ignite the lean mixtures especially at high pressures. One of the ways to realize a highly effective ignition process and proved combustion in engines is the nanosecond impulse discharge using as the ignition source [1]. The properties of such discharges in air at low and atmospheric pressure are widely discussed in literature [2]. But at high pressures, which are typical for engine operation, the experimental investigations of discharge dynamics are very restricted. To investigate the main discharge parameters at such conditions the numerical modeling must be used.

This study is devoted to the analysis of nanosecond discharge dynamics at high pressures. The numerical calculations of discharge properties in so-called hydrodynamic approximation have been performed. To describe discharge dynamics three-temperature four–liquid model of non-equilibrium plasma has been used [3]. The model includes the equations for electric potential, the balance equations for electron, positive and negative ions and excited molecules and the equations for vibration, electron and translational temperature. All the rate constants, cross-sections and ionization frequency were taken from the literature data [4], [5]. The rate coefficients of detachment reactions with negative ions O_2^-, O^- and excited molecules

$$N_2^*\left(A^2\sum{}_u^+\right), N_2^*\left(B^3\prod{}_g\right)$$

are varied in limits $1.9 \div 2.5 \cdot 10^{-9}$ cm^3/s [4]. In calculations the average rate coefficient of detachment reactions was used equals to $\alpha^* = 2 \cdot 10^9$ cm^3/s. The ionization enhancement due to vibration excitation was taken into account by multiplying ionization frequency on the special factor k_V as in [2].

On every iteration in time the voltage fall in the cathode layer was evaluated based on the average values of joule dissipation and currents. The evolution of electron energy distribution function in time was neglected and the ideal matching between pulse generator and evolving plasma was assumed. The voltage pulse has a trapezoidal form with linear rise over 2 ns, a 18 ns flat plateu and 2ns linear fall off. The maximum voltage was 30 kV. Effective secondary emission coefficient of γ = 0.1 was assumed. The efficiency of nanosecond discharge was evaluated by the ability to produce electrons during the pulse. The results of calculations have shown strong non-uniformity of discharge (Fig.1, Fig.2) connecting with the electron temperature and factor k_V varying. It has been obtained that at high pressures in the discharge area the electron concentration decreases with pressure increasing, but in the sheath layer the local increase of electron concentration is observed (Fig.1).

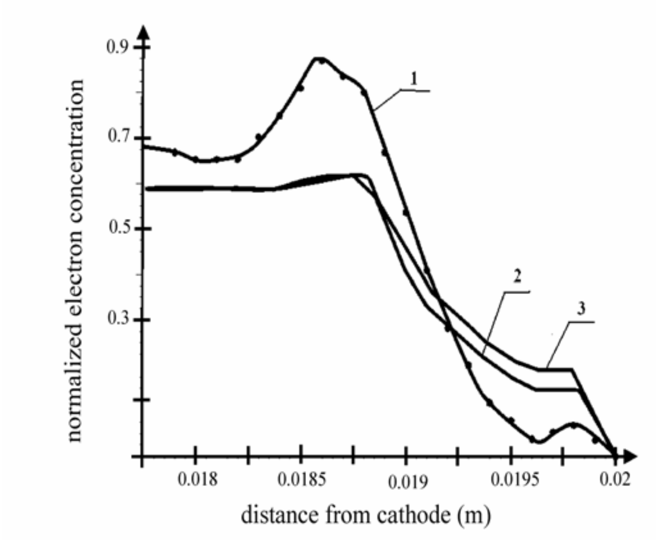

Fig.1. The profiles of normalized electron concentration at t = 2 ns: 1 - P = 0.1 MPa, 2 - P = 0.2 MPa, 3 - P = 0.3 MPa

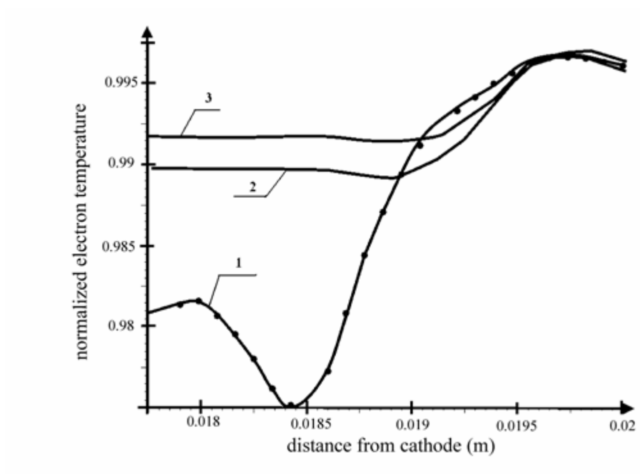

Fig.2. The profiles of normalized electron temperature at t = 4 ns: 1 - P = 0.1 MPa, 2 - P = 0.2 MPa, 3 - P = 0.3 MPa.

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Spectroscopic Diagnostics of Atmospheric Pressure Plasmas

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Plasma diagnostics are a necessary tool to understand the physical phenomena of plasmas. And also these techniques give a practical way to control plasma parameters and an essential tool to discover new plasma sources, which are appropriate for emerging new applications. Many different types of plasma diagnostics have been developed because plasmas are extremely complex media, which span a wide range of parameters. For example, the typical electron temperature of atmospheric pressure plasmas ranges from 5000 K to 100,000 K.

In this presentation, various diagnostic techniques will be reviewed and in particular spectroscopic methods will be highlighted. Three approaches, such as optical emission, absorption, and fluorescence, are also summarized with representative results that are taken from dielectric barrier discharges (DBD) [1], an atmospheric pressure plasma jet, and a microwave discharge [2]. The degree of thermal equilibrium will be discussed by comparing T_e, T_{exc}, T_{vib}, and T_{rot}.

T_e measurement [1]: The emission line intensities of N_2^* and N_2^+ from DBD are measured by an optical emission spectroscopic method. The emission intensity I_{N2*} of 337.1 nm wavelength is proportional to the product of a concentration of $N_2(C^3P_u)$ and a transition probability Q_{N2*} of $N_2(C^3P_u$ ® $B^3P_g)$. Generation of $N_2(C^3P_u)$ is the function of the cross section of electron-nitrogen interaction and an electron energy distribution function (EEDF), $f(e)$. Considering the emission intensity I_{N2+} of 391.4 nm wavelength with the same principle, the resultant intensity ratio of the spectral line from $N_2^+(B^2S_u^+$ ® $X^2S_g^+)$ to that from $N_2(C^3P_u$ ® $B^3P_g)$ is described by the following expression:

$$\frac{I_{N2+}}{I_{N2*}} = \frac{\int \sigma_{N2+} f(\varepsilon)\sqrt{\varepsilon}\, d\varepsilon}{\int \sigma_{N2*} f(\varepsilon)\sqrt{\varepsilon}\, d\varepsilon} \cdot \frac{Q_{N2+}}{Q_{N2*}} \qquad (1)$$

The calculation of emission intensity ratio, I_{N2+}/I_{N2*}, requires an accurate EEDF. In this work, a Boltzmann equation solver, ELENDIF, is employed to calculate the EEDF and resultant reaction rate coefficients.

The measured intensity ratio of N_2^+ to N_2^* lines depends on an electric field or an electron energy in the discharge. Hence, the values of electric field and average electron energy in each discharge system are determined by comparing the measured line intensity ratio with a numerical estimation made by a Boltzmann equation solver, ELENDIF.

T_{exc} measurement [2]: The excitation temperature (T_{exc}) describes the population of atomic excited states only if the distribution of the excited levels is Boltzmann. In order to evaluate the distribution type we used some of the Ar emission lines and applied the Boltzmann-fitting method. This method is commonly employed because it is rather simple to implement, but it does require a complete identification of a number of isolated lines. Assuming that a line's intensity is related to the population of the upper state, the probability of the transition (A_{ul}) and the energy of the emitted photon (hn_{ul}), it is given by

$$I \propto h\nu_{ul} A_{ul} g_u \exp\left(-\frac{E_u}{k_B T_{exc}}\right), \qquad (2$$

$$\ln\left(\frac{I}{h\nu_{ul} A_{ul} g_u}\right) \propto -\frac{E_u}{k_B T_{exc}}, \qquad (2a)$$

where g_u is the degeneracy of the upper state, k_B is the Boltzmann constant, h is the Planck constant, n_{ul} is the emission frequency, and E_u is the energy of the upper level. The Boltzmann method consists of plotting the left hand side (LHS) of eq. (2a) versus the energy of the upper state. All the points should fall on a linear distribution whose slope is inversely proportional to the excitation temperature.

T_{vib} and T_{rot} measurement [2]: A measurement of the rotational temperature can be extracted from the rotational C_2 Swan band. The C_2 molecule is formed by the interaction of the excited states of the Ar and H_2 plasma with the carbon particles. Usually the rotational temperature is related to the gas temperature because the spectrum is the result of collisions between heavy molecules/ions. Due to the high number of allowed transitions between the large number of rotational states, the spectrum has a high density of lines that in many cases overlap.

To properly determine the Swan spectrum, a high-resolution monochromator is required to disentangle the complex spectrum. With such a device, it is still possible to define a rotational temperature, even with a set of partially overlapped lines. For a determination of the temperature one compares the experimentally measured spectrum with theoretical spectra calculated for different temperatures.

Fig. 1 shows the rotational spectrum of C_2 molecules created using a microwave discharge of 400W in a mixture of 2% H_2 in Ar flowing at 10 lpm. Carbon particles were in the plasma region. The spectrum shown is actually the average of 10 separate spectra each with a 100 msec exposure time. The measured spectrum is normalized with respect to the theoretical band head. The spectrometer entrance slit was set to 5 mm. The resolution of the camera, even at 0.0108 nm/pixel, is not enough to completely resolve the fine structure of the C_2 band. Nonetheless, a significant number of lines resulting from the overlapping of the different branches, are quite well resolved. However, when examining the spectrum in detail, one finds that typically different triplets are not well resolved, with just a few individual lines being recognizable around 514.8 nm.

A close examination of the theory shows that some lines are not affected by temperature while others are. By identifying resolved nearby pairs of such lines and taking the ratios of their intensities, and doing this for both the experimental and theoretical spectra, one finds that one has a fairly sensitive means of determining temperature. The temperature determination is thus done by calculating the intensity ratios of such pairs of lines at different temperatures and adjusting the calculation temperature until one reproduces the experimental ratios. By adjusting the fitting parameters we find a good result with a rotational temperature of approximately 5400 K.

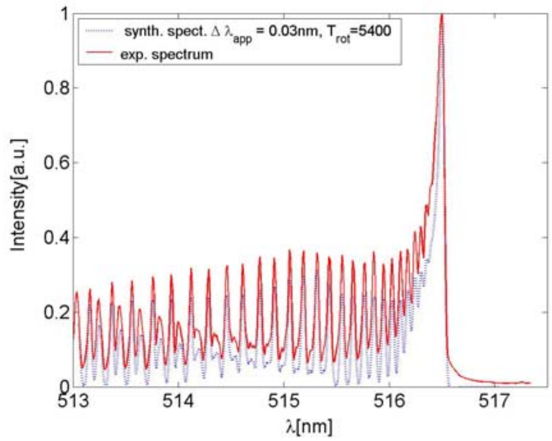

Fig.1. A comparison of the experimental spectrum (solid line, red) at Ar=10 lpm with 2% H_2 and 500 W plasma power with the synthetic one (dotted line, blue) for T=5400K and an assumed apparatus resolution of 0.03 nm

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Non-Thermal Plasma Hydrocarbon Cracking With Novel Electrode and Dielectric Arrangements

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In previous studies [1-5], we have shown that the treatment of hydrocarbon gaseous fuels (e.g., propane, ethane, butane) by a dielectric-barrier-discharge generated non-thermal plasma results in the ‘cracking’ of the hydrocarbon molecules into smaller fragments. It has also been show that, with flame studies of plasma- ‘activated’ gaseous fuels, flame stability can be improved (i.e., much leaner burning or increased blowout range) and flame velocity can be increased.

In Fig. 1 below, a typical dielectric-barrier-discharge plasma fuel-activator is shown. In this presentation, we will discuss methods of improving gaseous hydrocarbon-fuel cracking with novel arrangements of dielectrics and electrodes. Because of patent-application issues, we cannot discuss the details of our apparatus in this abstract. However, at the Workshop in September 2008, we will present details of the apparatus and test results for hydrocarbon cracking.

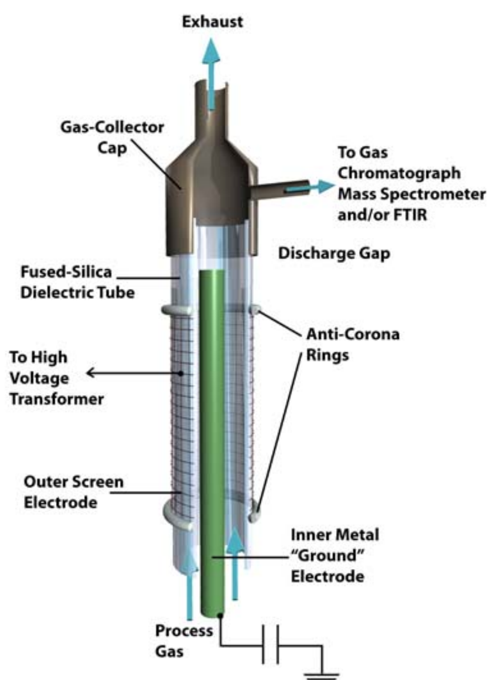

Fig. 1: Illustration of a typical cylindrical dielectric-barrier-discharge non-thermal plasma reactor used for gaseous hydrocarbon cracking

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Dr. Rosocha has presented many invited talks and served as a session chair, organizer, and committee member for several major international conferences and workshops, including organizing the 1st International Workshop on Plasma-Assisted Combustion in 2003, and co-organizing the 2nd event in 2006. He has served as a referee for several journals and was Associate Editor for Non-Thermal Plasmas for the Journal of Advanced Oxidation Technologies and has been a Guest Editor for two special issues of the IEEE Transactions on Plasma Science on Plasma-Assisted Combustion.

Dr. Rosocha is presently a member of the American Physical Society and the IEEE. He has previously been a member of the International Ozone Association, Sigma Pi Sigma, and Phi Beta Kappa.

Dr. Rosocha is now an independent consultant and his current R&D interests are focused on two of the most important problems of our time: CO_2 sequestration/global warming and national energy security (improving combustion, the efficiency of engines/fuels, and the conversion of trash into ‘green’ energy).

Experimental Investigation of the Hybrid Type Plasma Assisted Combustion and Reformation System

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The triple vortex plasma assisted combustion and reformation system consists of an inductive RF heater and a number of high voltage DC plasma torches [1]. These torches serve to feed fuel and additional reagents into the system and for initial media ionization inside the reactor. The system will operate 1) as a multi-mode, multi-purpose reactor in a wide range of plasma feedstock gases and turn down ratios, and 2) as a suitable mean for the multiple reagents such as natural gas, liquid fuels, coal, and air simultaneously feeding into the discharge zone [2-6]. The reverse and direct vortex air streams are injected separately through the tangential channels of vortex generators located near the exit nozzle and the bottom portion accordingly.

The hybrid type plasma assisted combustion and reformation system ensures operation in two basic modes: gasification and combustion. At the first stage of experiments, equipment check-out, approbation of sampling schemes, definition of stability operation range, and evaluation test of combustion system without steam injection were carried out. At this stage inductive radio frequency (RF) devices were not tested. Propane, injected into the plasma torch with air, was used as a hydrocarbon material. Additional vortex generator for air feeding has been installed in the bottom part of a triple vortex combustor with internal diameter of 73 mm.

In Fig. 1 temperatures of the bottom part (T_b), cylindrical wall (T_w) of a triple vortex combustor, and also NO_x and CO exit concentrations as the functions of total air excess coefficient are shown. During conducted tests, plasma feedstock air flow rate was kept constant and equal 0.514 g/s, main (ensuring a reverse stream) air flow rate varied from 6.59 to 28.59 g/s, air flow rate through the bottom vortex generator varied from 0 to 5.23 g/s, and propane consumption changed from 0.085 to 0.48 g/s.

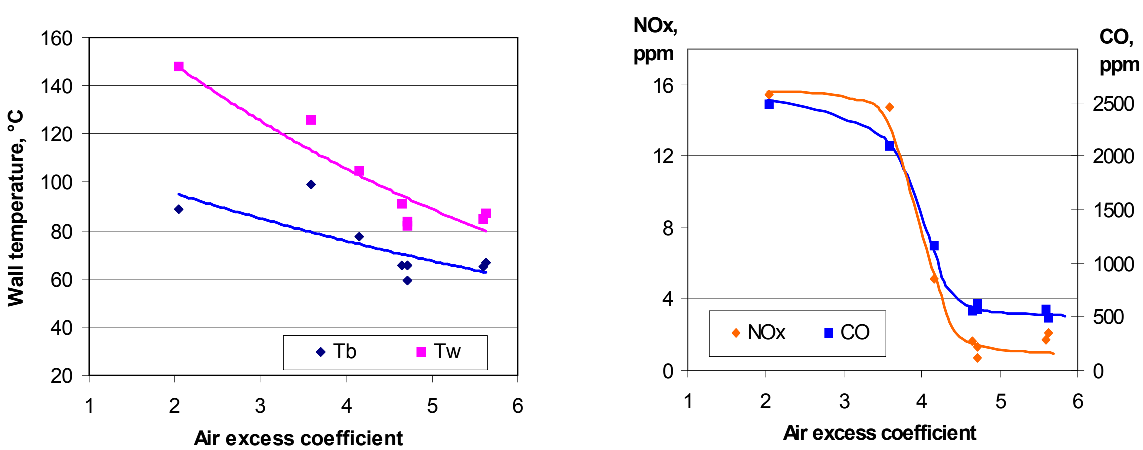

Fig.1. Wall temperatures, NO_x and CO concentrations as functions of total air excess coefficient

In all experiments with propane burning the power, consumed by a plasma torch, was 88 W at electric current 80 mA. Maximum wall temperatures did not exceeded 150 °C at the air excess coefficient equal to 2.04 and 90 °C at the air excess coefficient 5.59, what confirms the combustion system cooling effectiveness and possibility of low-cost materials application.

The level of nitrogen oxides emission at the combustion system exit measured by TESTO-350 XL gas analyzer was pretty low. For the air excess coefficient $\lambda = 2.04$, it was equal to 15.4 ppm, for $\lambda = 5.59$ diminished to 1.7 ppm and even lower. Since the experiments were held at near atmospheric pressure conditions inside the combustor, CO emission level was pretty high - 572 ppm with air excess coefficient $\lambda = 5.59$. This fact leads to the necessity to optimize the combustor's geometry, improve mixing processes and optionally in some cases utilize the catalytic neutralization method to reduce unburned CO.

On the second stage of conducted tests an influence of steam injection into the triple vortex combustor for the purposes of further application for gasification modes was investigated. In this case a bottom air swirler was replaced by a steam feeder. In Fig. 2 the wall (T_b, T_w) and exit temperatures T_{exit}, NO_x and CO concentration as the functions of steam flow rate are presented.

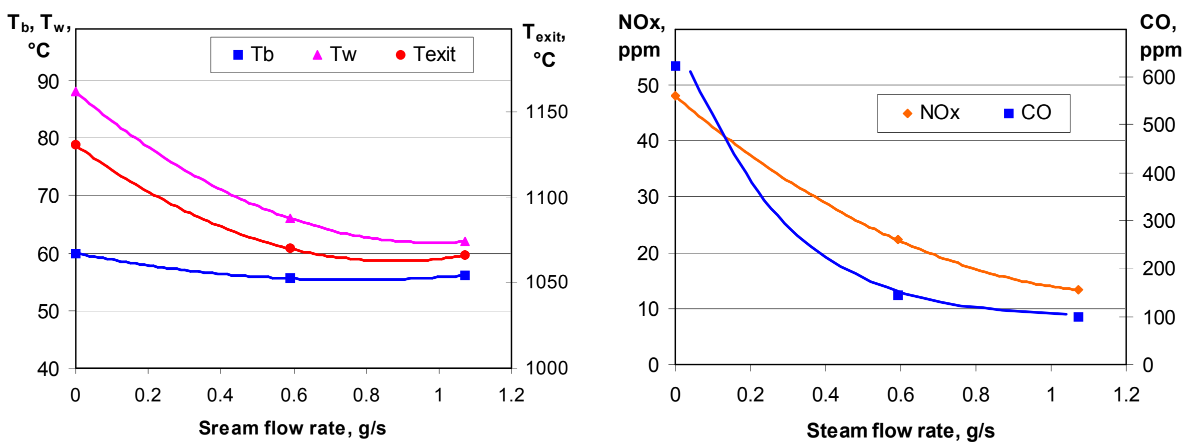

Fig. 2. The wall and exit temperatures, NO_x and CO concentrations as the functions of a steam flow rate

During the tests the certain parameters were hold constants: plasma feedstock air flow rate 0.443 g/s, main air flow rate 7.156 g/s, propane consumption 0.34 g/s. These parameters correspond to total air excess coefficient $\lambda = 1.47$. Steam flow rate varied from 0 to 1.07 g/s, power consumed by the plasma torch, was about 56 W at electric current 45 mA. It was mentioned that the increase of a steam flow rate reduces the combustor wall and exit temperatures, and also decreases nitrogen oxide emissions. For operation modes with near-stoichiometric air excess coefficient, a steam injection results in some reduction of CO emission at the combustor exit, while in lean mixtures a steam feeding slightly augments the CO concentrations.

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Dr. Serbin is the Academician of Academy of Shipbuilding Sciences of Ukraine and International Academy of Maritime Sciences, Technologies and Innovations.

Theoretical Investigation of the Physical and Chemical Processes in a Liquid Fuel Plasma Assisted Reformer

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Hydrocarbon reformation is the major method of hydrogen production. There are numerous well-known technical solutions for atmospheric pressure fuel reformation, including plasma based. At the same time there is no any small-scale liquid fuel reformer on the market yet. Applied Plasma Technologies (APT) proposes the fuels reformation technology development as a combination of two innovative modules: improved triple flow vortex reactor and plasma torch with incorporated fuel atomizer.

The first module will be based on the reverse vortex combustor prototype. Several reverse vortex combustors based on triple vortex technology have been engineered, manufactured and tested by APT within last three years [1-6]. The second module will serve simultaneously for fuel atomizing, ignition, and flame control, and will implement a transitional non-thermal glow to spark discharge. There are two options to utilize this discharge: (1) in the form of a continuously operating plasma pilot with fuel feeding into the arc chamber [7] or (2) as a spatial, rotating, transient discharge in the entire reactor volume [5].

With the use of the ANSYS Fluent CFD-computation program preliminary axi-symmetric calculations with a swirl dominated flow inside the plasma assisted reformer (PAR) have been conducted. The configuration of interest is a combination of a plasma pilot and reformer chamber that has cylindrical and conical parts (Fig. 1).

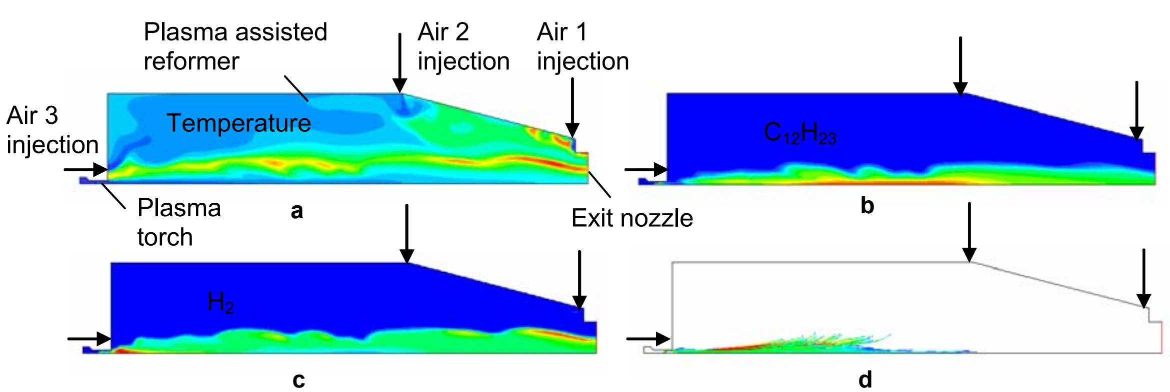

Fig.1. Contours of temperature (a), mass fraction of $C_{12}H_{23}$ (b), H_2 (c), and particle traces (d) colored by particle diameter inside the PAR with axial fuel injection.

The liquid fuel $C_{12}H_{23}$ is supplied through the plasma torch. Air for direct and reverse vortices is supplied into the chamber through three swirlers. The swirler 1 is located on the conical wall near the chamber exit. The swirler 2 is located at the intersection of the cylindrical and conical walls. The swirler 3 is located on the injector face of the plasma torch. The simulations were performed using RANS approach. The turbulent viscosity was computed using RNG k-e turbulence model. There are seven species O_2, CO_2, CO, H_2O, H_2, $C_{12}H_{23}$, N_2. In cases when the reactions are modeled a five step simple kinetic mechanism was used. Similarly, the turbulent combustion is modeled using Eddy Dissipation Concept (EDC) closure. The mass flow rate through each of the swirlers 1 and 2 is 5 g/s with the injection angle of 45 deg. in the radial and circumferential directions. The mass flow rate in the swirler 3 is 10 g/s and has the injection angle 45 deg in the axial and circumferential directions.

Fig 1 presents the results of simulation when fuel is supplied in axial direction with mean velocity 5 m/s and air is injected by all three swirlers. The equivalence ratio of kerosene-air mixture is 1.42. Shown are the contours of temperature (a), mass fractions of $C_{12}H_{23}$ (b) and H_2 (c), and particle traces (d). Gasification and the liquid fuel partial oxidation chemical reactions are carried out in paraxial zones determined by exit nozzle diameter.

For detailed investigation of the kinetic mechanism of liquid n-heptane (C_7H_{16}) partial oxidation corresponding calculations of molecular hydrogen and carbon oxide exit concentrations from PAR are carried out using the Chemkin chemical kinetic software. Air and gas consisting of 90 % O_2 and 10 % N_2 are used as working medium. For the chemical processes investigations the kinetic scheme [8] with 160 components and 1540 reactions has been used.

The electric arc channel and mixing chamber of the plasma pilot, and PAR are modeled as perfectly stirred reactors. The electric arc channel's volume is 1.8 cm^3; heat power 300 W; feedstock gases: air or mixture of 90 O_2 and 10 % N_2 with flow rate 0.5 g/s and temperature 290 K. The plasma pilot mixing chamber's volume is 0.785 cm^3. Heated feedstock gases from the electric arc channel and n-heptane C_7H_{16} with temperature 290 K are injected into the mixing chamber. PAR's volume is 1255.0 cm^3. Products from the mixing chamber, air or gas consisting of 90 % O_2 and 10 % N_2 with temperature 300 K and flow rates 20 or 4 g/s accordingly, and steam with temperature 400 K are injected into the PAR. Pressure in the reformer is atmospheric.

The dependences of molecular hydrogen H_2, carbon oxide CO, methane CH_4 mole fractions, and exit reformer temperatures T at different fuel consumption $G_{nheptane}$ and steam flow rates G_{steam} through the reformer are presented in Fig. 2-3.

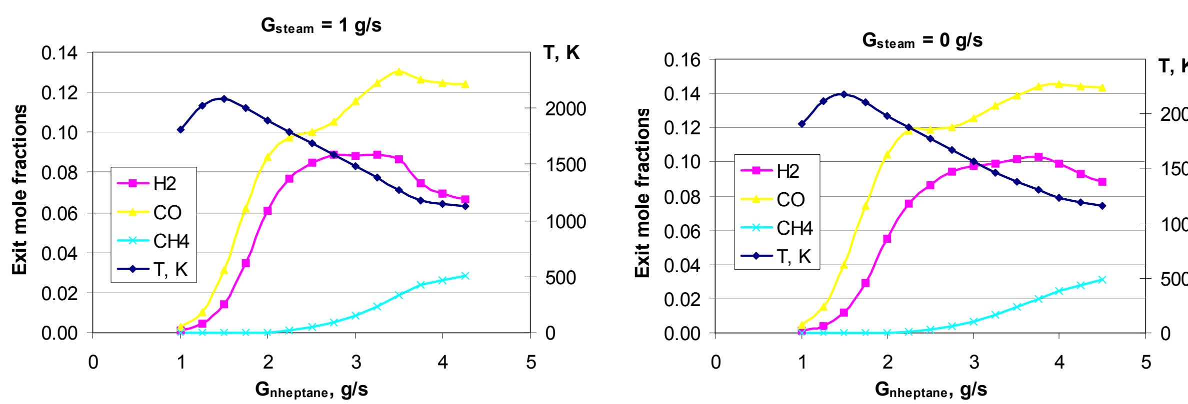

Fig.2. H_2, CO, CH_4 concentrations and temperature as functions of fuel consumption.
Working medium – air, total flow rate 20.5 g/s.

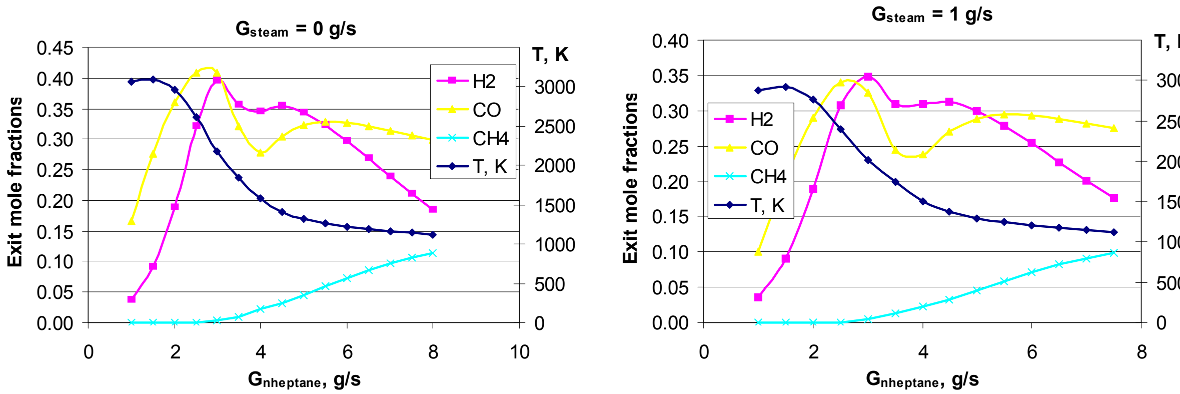

Fig.3. H_2, CO, CH_4 concentrations and temperature as functions of fuel consumption.
Working medium – 90 % O_2 and 10 % N_2, total flow rate 4.5 g/s.

At air flow rate through the reformer 20 g/s and heptane consumption through the plasma pilot 3.75 g/s the maximum hydrogen and carbon oxide concentrations are 10.3 and 14.5 % without steam injection; exit temperature is equal to 1302 K. At mixture (consisting of 90 % O_2, 10 % N_2) flow rate through the reformer 4 g/s and heptane consumption 3 g/s the maximum H_2 and CO concentrations are 39.6 % and 40.9 % without steam injection; exit temperature is equal to 2178 K. Under considered conditions steam adding always leads to lowering of maximal H_2, CO, and CH_4 concentrations. It can be explained on the basis of temperature decrease inside the PAR.

The results of numerical simulations demonstrated significant dependence of the PAR working process on the flow and chemical regimes. A future combined experimental and computational analysis will aim to advance the existing design by significant reduction of volumetric and gravimetric parameters, increase the hydrogen output, providing multi-fuel operation with a "cold walls" mode, and reduction of chocking and soot deposition.

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Study of Plasma Conversion of Ethanol into Syngas in Dynamic Plasma-Liquid Systems

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Plasma-assisted reforming of bio-fuels today is of great interest and importance. Therefore research of new and efficient plasma-fuel conversion processes is very actual [1]. In this work we continue our studies related to the plasma reforming of ethanol in dynamic plasma-liquid systems (PLS) using dc electric discharges in a gas channel with the liquid wall (DGCLW) [2]. The process of production of hydrogen-enriched synthesis gas (syngas) in the PLS-DGCLW in air–ethanol-water mixtures was investigated both experimentally and theoretically, using available diagnostics and numerical models, and the energy efficiency of this process was compared with other known plasma-fuel reforming methods. Although there is a lot of research needed before new technology can be made technically viable, our plasma-fuel reforming method looks very promising.

Fig. 1 shows the schematic of the DGCLW with two different schemes of electrodes: (a) solid electrode + liquid cathode or anode, and (b) two solid electrodes when gas plasma channel formed by the counter-flow air streams between electrodes. Fig. 2 shows typical current-voltage characteristics of the DGCLW in ethanol-water solution 5:1 for three different modes: (1) liquid cathode; (2) liquid anode; and (3) two solid electrodes. The electric discharge power, gas flow rates, ethanol-water mixing ratio and processing time were varied to optimize the process.

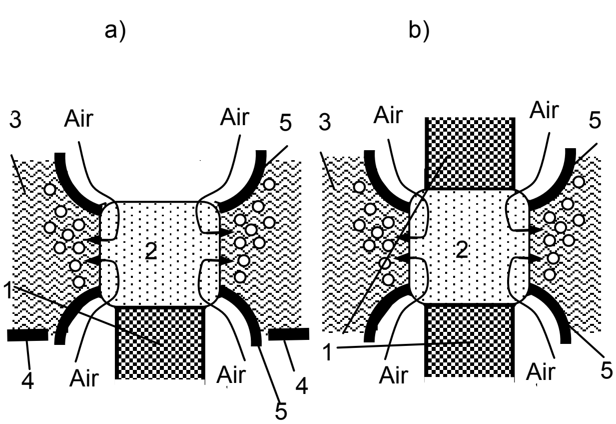

Fig. 1. Basic schemes of DGCLW

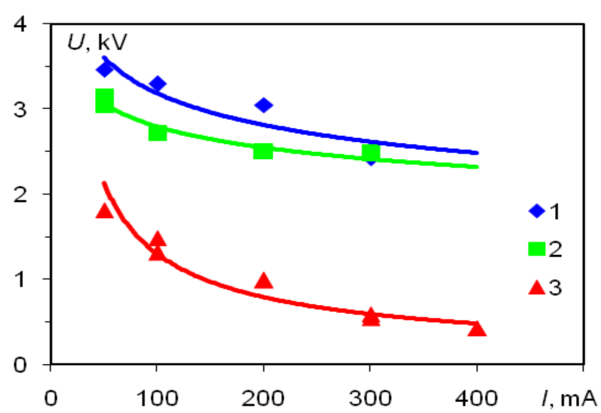

Fig.2. Current-voltage characteristics of DGCLW

Fig. 3 illustrates optical emission spectroscopic diagnostics of discharge plasma during the ethanol processing: fragment OES measurements vs. SPECAIR simulations (analytical N_2, CN, C_2, OH bands). Fig. 4 gives results of gas-chromatography for basic components of output syngas products: H_2, CO, CH_4, C_2H_2, C_2H_4, C_2H_6, CO_2, H_2O and N_2.

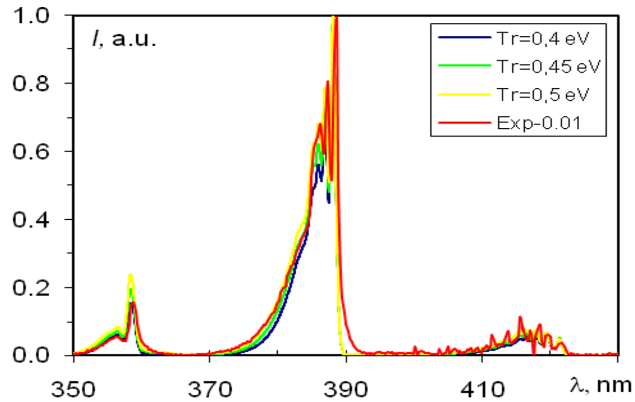

Fig.3. Emission spectrum of discharge plasma

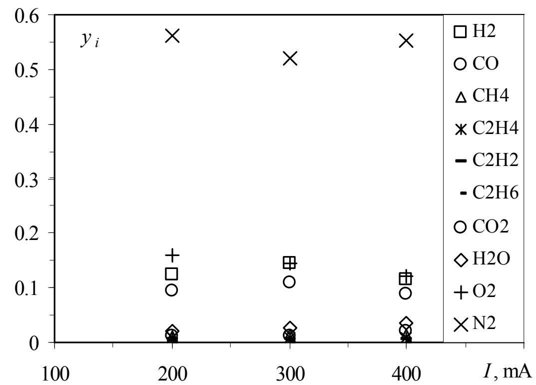

Fig.4.Gas-chromatography of syngas products

Fig. 5 presents comparison of the component content of syngas products obtained at measurements and calculations for different regime parameters. Fig. 6 demonstrates the efficiency of ethanol conversion into syngas by the DGCLW in ethanol-water solution 5:1 for different operational modes with (1) liquid cathode, (2) liquid anode, and (3) two solid electrodes.

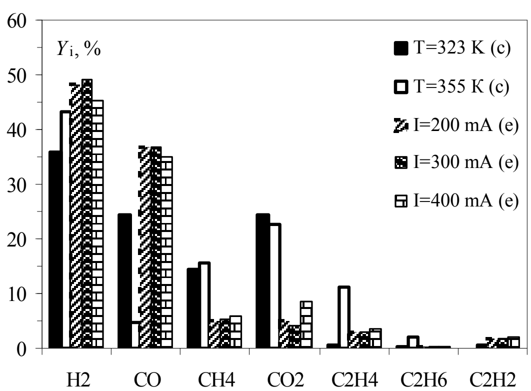

Fig.3. Emission spectrum of discharge plasma

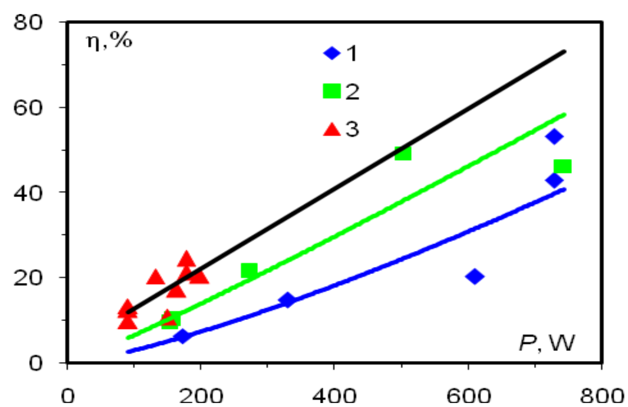

Fig.4.Gas-chromatography of syngas products

One can see the energy efficiency of the proposed method grows with the deposited electric power up to ~50-55%. These numbers correlate with out earlier results [2] and comparable with the best known plasma-aided ethanol reforming methods [1].

In summary, we conclude:

1. A dynamic PLS with the DGCLW is quite efficient in plasma conversion of ethanol into syngas. The most effective is the DGCLW with air streams between two solid electrodes.

2. The main components of syngas produced from ethanol in the DGCLW are H_2 and CO which relative yield is many times higher than for other hydrocarbons CH_4, C_2H_2, C_2H_4, and C_2H_6. The net yield of H_2 increases with increasing electric discharge power.
3. The numeric plasma-chemical kinetic modeling in air-water-ethanol system is in a fairly good agreement with experimental data, at least, for the main components of plasma and syngas.

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Application of Different Oxidants for Plasma Coal Gasification

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This paper presents the results of numerical experiments to validate the influence of different oxidants on the syngas composition, process temperature level, specific power consumption, coal gasification degree and efficiency of coal plasma gasification process. Powder River Basin bituminous coal of 6.8% ash content was taken for plasma gasification simulation.

Numerical experiments were conducted for the combined plasma gasifier (Fig. 1). This is an entrained flow gasifier with plug flow. A mixture of pulverised coal and gas oxidant is fed into the electric arc area through the inlet 4. Heat absorption by solid fuel and gas streams occurs in the same volume. The gasifier internal diameter was 0.15 m and its height 0.3 m. The alternative current arc establishes as sketched between two rod electrodes 5 and the graphite ring electrode 6. It is localised at the ring electrode width of 0.07 m by surrounding electromagnetic coil 2, fabricated from the water-cooled copper pipe.

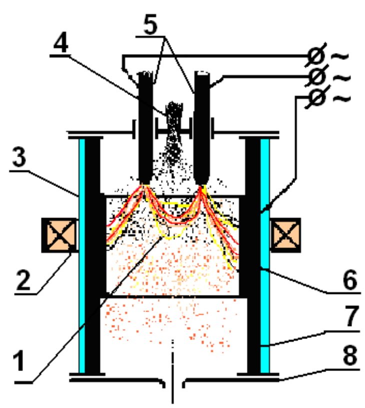

Fig. 1. Combined plasma arc gasifier:
1 – electric arc; 2 – electromagnetic coil; 3 – cylindrical water-cooled jacket; 4 – pipe for pulverised coal and gas injection; 5 –graphite rod electrode; 6 – graphite ring electrode; 7 – graphite lining; 8 – graphite orifice

The numerical experiments were conducted with the aid of computer code Plasma-Coal [1]. It was designed for computation of the processes of the moving, heating and kinetics of thermochemical conversion of coal-oxidant mixture in a plasma gasifier alike shown in Fig. 1. In the bases of this code is a one-dimensional model, which describes a two-phase chemically reacting flow with an internal plasma source.

Computations of coal plasma gasification were performed for seven different oxidants (see Table 1), applicable as the gasifying agents. Criterion of the calculations completion was achieving of 100 % carbon gasification degree within 0.7 m of the gasifier reacting zone's given length. To adjust this condition, the plasma gasifier power consumption (P_{arc} in Table 1) varied between 5 and 170 kW, depending on the used oxidant. Hereby the emission of heat due to the electric arc has been depleted by the gasifier length of 0.3 m. Thus processes of air (1), steam/carbon dioxide (2), carbon dioxide (3), steam (4), steam/air (5), steam/oxygen (6), and oxygen (7) gasification of coal were investigated.

Table 1. Initial systems composition for simulations and power inputs.

Process / **Consumption, kg h^{-1}**	**Coal**	**N_2**	**O_2**	**CO_2**	**H_2O**	**P_{arc}, kW**
1	36	92.4	27.6	0	0	131
2	36	0	0	38.0	16.00	141
3	36	0	0	77.0	0	170
4	36	0	0	0	31.0	110
5	36	40.0	11.95	0	16.0	110
6	36	1.3	11.9	0	16.0	63
7	36	3.1	27.6	0	0	5

Table 2 summarises the composition of the gas on the gasifier exit for all considered gasification regimes. Normalized by the mass of the syngas produced the specific power consumption values increase along the gasifier initial zone on the length by 0.3 m. This distance corresponds to completion of heat emission from the electric arc (Fig. 2).

Table 2. Gas composition at the gasifier exit, vol. %

Process	**CO**	**H_2**	**N_2**	**Other**
1	33.4	9.7	55.2	1.7
2	65.2	34.0	0	0.8
3	84.6	14.8	0	0.6
4	46.2	51.4	0	2.4
5	39.5	30.0	28.9	1.6
6	56.0	41.2	1.3	1.5
7	72.7	23.4	3.8	0.1

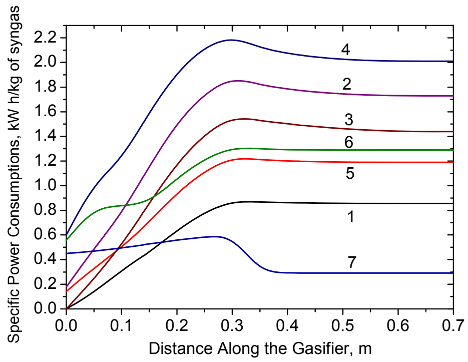

Fig. 2. Specific power consumptions along the gasifier: 1-7 – see Table 1

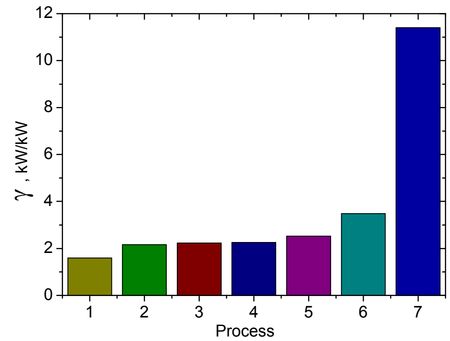

Fig. 3. Gasification efficiency. Numbers on the abscissa axis correspond to Table 1

The downtrend of the specific power consumptions after passing the maximum comes out due to the continuation of the carbon gasification reactions and heat emission due to its oxidizing into carbon monoxide. This effect is the most sharply defined during the oxygen gasification of coal (curve 7). Comparing curves 1 to 7, it may be seen that maximal values of power consumption correspond to coal gasification in steam medium (curve 4), and minimal ones – to oxygen gasification (curve 7). Specific power consumptions' independence on coordinate along the gasifier after 0.5 m is a consequence of all gasification reactions completion (Table 2).

The criterion of energy efficiency of the solid fuel gasification process is the relative thermal power of produced syngas. In accordance with the following formula, the relative thermal power of syngas (γ) can be defined as a ratio of syngas specific heat value (Q_{SYNGAS}, [kJ·kg^{-1}]) multiplication by mass flow (G_{SYNGAS}, [kg·s^{-1}]) to total consumed power ($P_{arc} + Q_{H2O}{\cdot}G_{H2O} + Q_{O2}\,G_{O2}$, [kW]).

$$\gamma = \frac{Q_{SINGAS} \cdot G_{SYNGAS}}{P_{arc} + Q_{H2O} \cdot G_{H2O} + Q_{O2} \cdot G_{O2}} \quad \text{[kW/kW]}.$$

From Fig. 3 one can see that minimal relative thermal power of produced syngas corresponds to air gasification of coal and maximal one – to oxygen gasification of coal.

In the dependence on the function of syngas, either process from Table 2 can be preferable despite of its efficiency. For instance, to feed fuel cells the process 4 is more preferable due to maximal concentration of hydrogen and absence of ballast impurities. At the same time, the process 7 will be preferable for power generation. Note that obtained results are applicable to any kind of solid fuel, which organic mass composition can be specified by the set of the functional groups (CO, CO_2, CH_4, H_2O, and tar) and carbon.

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Plasma-Fuel Systems for Coal Fired Thermal Power Plants

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To increase efficiency of solid fuel utilization, to decrease share of fuel oil and natural gas in fuel balance of Thermal Power Plants (TPP) and to decrease harmful emissions plasmachemical technology of coals ignition, gasification and combustion were developed. Plasma-fuel systems (PFS) were created to realize this technology. PFS are a combination of pulverized fuel burners with DC arc plasma torches. The main idea of PFS is to replace fuel oil or natural gas by products of plasmachemically processed pulverized coal. It was experimentally proven that PFS use increases efficiency of coal ignition and combustion, eliminates fuel oil expenditure for starting up and flame stabilization, decreases unburned carbon, NOx, SOx, V_2O_5 emission, and provides ample scope for the process automation.

PFS have been tested for boilers start up by plasma ignition of pulverized coal and flame stabilization in different countries at 29 power boilers steam-productivity 75 to 670 t/h equipped with different types of pulverized coal burners (direct flow, muffle and swirl burners). At PFS testing power coals of all ranks (brown, bituminous, anthracite and their mixtures) were incinerated (Table 1). Volatile content of them was from 4 to 50%, ash varied from 15 to 56% and heat of combustion was from 1600 to 6000 kcal/kg. The advantages of PFS technology were confirmed by 3D simulation of the boilers equipped with PFS.

Table 1. Technical characteristics of coals

Coal type	W^w	A^d	V^{daf}	Q_l^w **(kcal/kg)**
Brown	25-35	15-20	35-50	3000-3800
Lignite	32-40	28-35	23-27	1900-2100
Shale oil	40-50	75-80	48-50	1600-2000
Bituminous	5-12	20-56	15-40	3500-5000
Anthracite	5-8	25-35	4-10	4300-6200
Coal mixture	10.4	48.5	38.2	3150

(Nomenclature: W^w = wet per working mass; A^d = ash per dry mass; V^{daf} = volatile per dry ash-free mass; Q_l^w = low heat of coal combustion per working mass).

Using PFS fuel oil is replaced by pulverised coal, which is a subject to a thermochemical pre-process to the combustion within the PFS. In this technology part of the coal/air mixture is fed into the burner where the plasma-flame, having a locally high concentration of energy, induces gasification of the coal and partial oxidation of the char carbon. The resulting coal/air mixture is deficient in oxygen, the carbon being mainly oxidized to carbon monoxide. As a result, a highly reactive mixture of combustible gases (at a temperature of about 1300 K) and partially oxidized char particles are obtained at the exit of the burner. On entry to the furnace, this combustible mixture is easily ignited. This allows prompt ignition and much enhanced flame stability of the main portion of the coal flame which is not directly treated by the plasma. Activation of coal combustion by this means eliminates the need for supplementary fuel consumption (fuel oil or natural gas), traditionally used for the start-up of a coal-fired furnace. Figs.1 and 2 illustrate the process of thermochemical preparation of coal to combustion. The figures present schemes of the main types of the developed direct flow and swirl PFS.

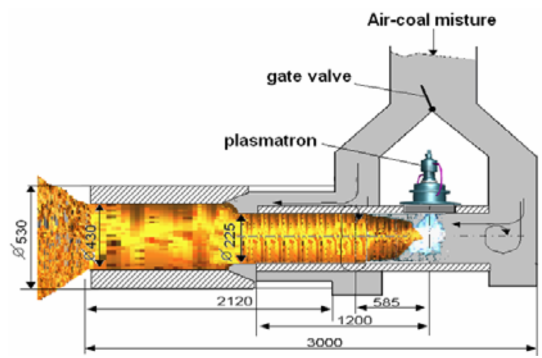

Fig. 1. Tangential flow PFS

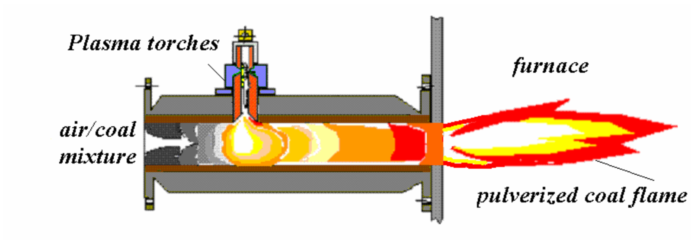

Fig. 2. Direct flow PFS

Recent interest to the application of the PFS at TPP increases except China where 87 % of electrical power is produced at coal fired TPP in Kazakhstan, Russia, Turkey, Korea, and India in which segment of pulverized coal fired TPP in power engineering is 80, 30, 47, 50, and 70% correspondingly. At present for some of these countries TPP PFS with DC plasma torches of 200 kW power are projected. The projects are being fulfilled for the boilers of steam productivity of 75 to 800 t/h at Shekhtinsk TPP (Kazakhstan), Reftinsk TPP (Russia), Shan-si TPP, and South See – Tzin-nen TPP (China). Figs. 3 and 4 illustrate technical decisions of PFS application for boilers by ongoing projects.

Fig. 3 illustrates cross section of the RFK-210 boiler of 210 MW power. Flow rate of lignite for this boiler is 250 t/h (Table 1). 48 direct flow pulverized coal burners are mounted on the boiler. The burners are distributed in 4 layer by 6 units. 12 plasma torches are mounted into muffle channels of the burners of the lower layer, ensuring ignition of lignite of 7.25 t/h consumption through the channel.

Scheme of the PFS arrangement on one furnace of the two-furnace boiler PK-39-II of 300 MW power is shown in Fig. 4. Bituminous coal flow rate for one furnace of the boiler is 83 t/h. The furnace is equipped with 12 tangential pulverized coal burners by 6 burners front side and backside in two layer. Coal flow rate through the burner is 7 t/h. 6 main burners are being reequipped with 6 tangential flow PFS which will guarantee oil free boiler start up and pulverized coal flame stabilization.

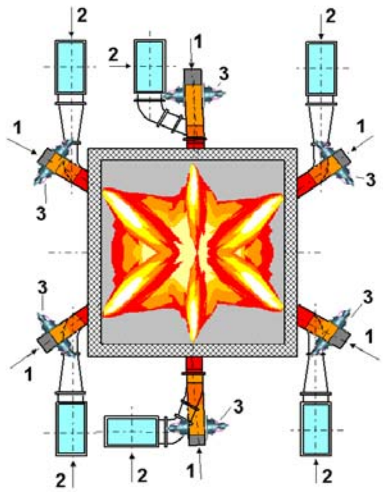

Fig. 3. Overview of the PFS on the 210 MW boiler furnace (Yatagan TPP, Turkey, project): 1 – air/coal mixture, 2 – secondary air, 3 – plasma torches on direct flow PFS

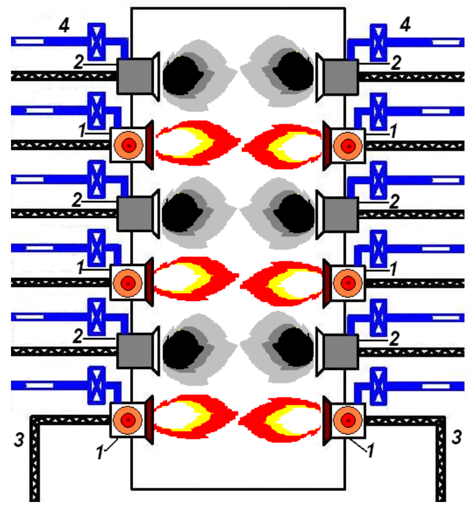

Fig. 4. Assembling of the PFS at a furnace of the two-furnace boiler 800 t/h (Reftinsk TPP, Russia) : 1 – swirl PFS, 2 – main pulverized coal burner, 3 – air/coal mixture, 4 – secondary air

Conclusions:

Plasma-fuel system (PFS) provides reliable ignition of any coal and improves combustion efficiency at the long term operation mode. PFS eliminates the need of supporting fuels (gas and oil) for the boilers start up and flame stabilization. PFS could reduce the boiler emissions (NOx, unburned carbon, etc.) in the case of continuous flame control.

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Studies of Plasma Assisted Coal Gasification for Syngas Production

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Nowadays, the processing technology of carbon containing fuels is looking for to the development of new equipment and processes, that are environmentally clean, automated and that outweigh the traditional chemical methods. In this scope, plasma gasification has been shown to be an innovative technology that can transform high calorific waste into valuable syngas and a vitrified slag by means of thermal or non-thermal plasmas. Particularly, in the field of coal gasification, this technology can be used in order to increase the production rate of gaseous fuels that can be employed in combustion systems such as gas turbine for energy generation. Indeed, conventional coal gasification processes do not allow a maximum coal conversion, generating a syngas with low calorific value. It is known that to increase the calorific value of syngas it is necessary to increase the formation of H_2 in detriment of the formation of CO. A classic form to shift the equilibrium in favour of H_2 is injecting water steam at high temperature, a method which is of high cost and high energy demanding. The idea of this work is to inject low temperature (about 150°C) water steam directly into the plasma torch. The reaction of the plasma with the water steam will produce, in a more efficient way, much more chemical reactive species than are produced in high temperature steam. With that, it is expected the calorific value of gasification gas to increase at a lower cost compared with the conventional processes. To investigate this process a mass spectrometer and a gas analysis system was adapted to the gas exit of a laboratory scale gasifier which includes a plasma torch installed on the coal burning region (Fig. 1). The results indicate an increase, up to 10%, for the H_2 and CO species when the plasma is switched on. It is also observed that the plasma decrease the amount of H_2O specie more than one order of magnitude, indicating that the water vapor has been consumed in reaction with coal to form CO and H_2 species (see Fig. 2).

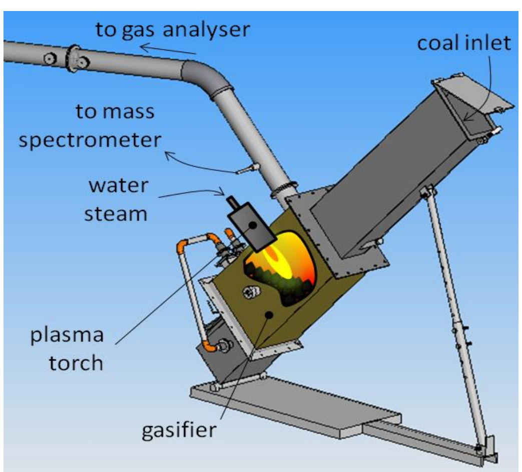

Fig.1.Experimental apparatus mounted for analysis of the plasma assisted coal gasification.

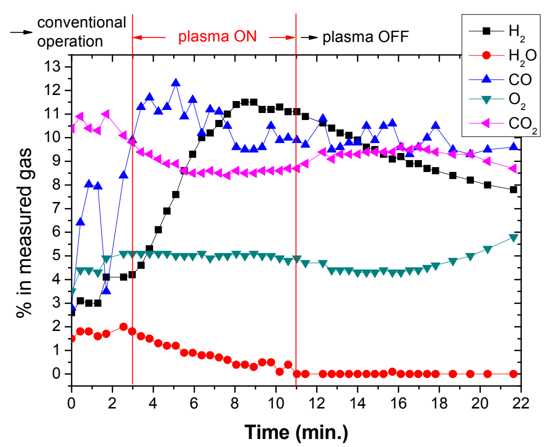

Fig.2. Temporal evolution of H_2, H_2O, CO, O_2 e CO_2 species measured before and during the process of plasma assisted coal gasification.

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Mass Spectrometry Studies of Partial Oxidation of Methane in a Gliding Arc Reactor

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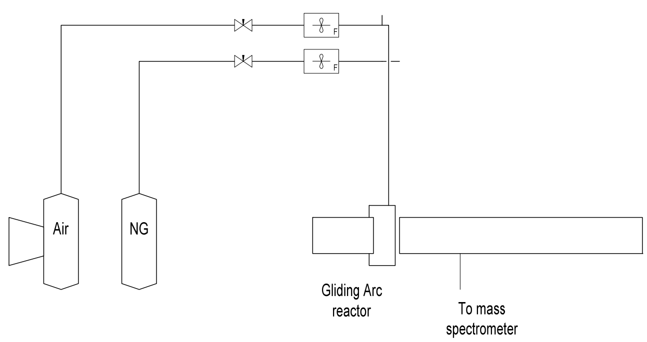
In order to better use all energetic potential of methane, different technologies have been used to convert it in more useful chemical byproducts. The most important route of methane utilization is its oxidation, aiming at the formation of synthesis gas (syngas). Syngas, a combination of H_2 and CO, is used in a variety of petrochemical processes such as methanol production via the so-called Fischer–Tropsch synthesis. Among the processes used in methane conversion, the gaseous plasma is effective in producing active species including electrons, ions, and radicals, to promote chemical kinetics of the process. Thus, a large number of studies of the methane reaction using various types of plasmas have been intensively carried out, especially with non-equilibrium plasma. Gliding arc discharge is a new alternative method for generating non-equilibrium plasma with high energy efficiency and environmentally friendly.

In this work, a gliding arc plasma vortex (Fig. 1) was used to promote the partial oxidation of methane. The gliding arc discharge was generated with a mixture of air + natural gas (NG) using an a.c. power source (60Hz) with power ranging from 2.3 to 4.6 kW. During the experiments, the air flow was set at 1.6 g/s and the natural gas flow varied from 0.1-0.3 g/s, giving an equivalence ratio ranging from 1.1 to 3.2. The generated/consumed species in the gas phase were real-time monitored by mass spectrometry. The results indicate that the NG species (basically hydrocarbons) is converted mainly in H_2, CO, and CO_2. Unfortunately the mass spectrometry do not allow us to quantify the real amount of each species that is being formed, but is noted that H_2 presents the higher partial pressure followed by CO and very small values for CO_2, indicating that syngas has been produced. This preliminary studies on NG conversion by plasma show that: i) the methane conversion rate ($1-CH_{4initial}/CH_{4final}$) decreases with the increase of NG flow rate (Fig. 2), due to the reduction of residence time of methane species inside the plasma region and also by the displacement of stoichiometry condition (equivalence ratio equal to 1), where the methane is completely consumed in the combustion with air and ii) increasing the applied power in the discharge leads to an increase in the methane conversion rate due to the increase of its reactivity.

a)



b)

Fig.1: a) Gliding arc reactor, b) Experimental apparatus

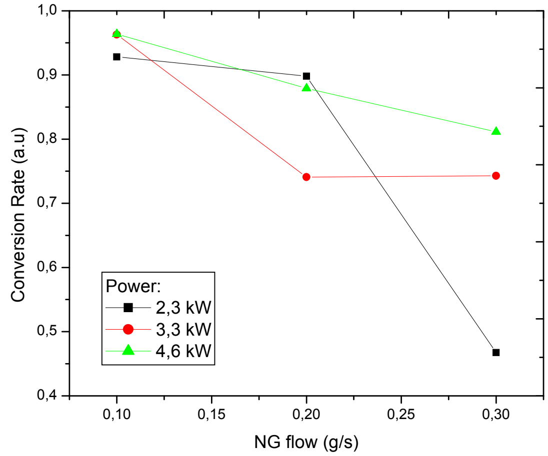


Fig.2. Conversion rate in function of NG flow for different power

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Gasification of Solid Fuels Using Entrained Plasma Reactor

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One of the perspective technologies of effective and environmentally friendly solid fuels utilization is the plasma gasification for synthesis gas production. This paper describes numerical and experimental investigations of coal air and water steam gasification at arc-plasma gasifier. First the processes of gasification were investigated numerically with the aid of a universal thermodynamic code TERRA and one-dimensional kinetic code Plasma-Coal. Kazakhstan Kuuchekinski bituminous coal of 40% ash content was used for the investigation (Table 1). Concentrations of the processes products, specific power consumptions, gasification degrees, temperatures of the products were found and analysed. Then the coal-oxidant mixtures were investigated experimentally and the numerical results were validated against operational data obtained in the experiments. Special plasma reactor for coal gasification allows performing processes thermo impact on coal for getting synthesis gas ($CO+H_2$) from organic part of coal that is free from nitrogen and sulphur oxides. The experimental installation is intended for work in range of power 30-100 kWe, mass averaged temperatures 1800-4000 K, coal dust consumption 3-12 kg/h and gas-oxidant (air or steam) flow 0.5-15 kg/h. Measures of concentration values of coal plasma gasification gaseous products, values of coal gasification degree, and mass average temperature of coal gasification were fulfilled.

Table 1. Solid fuels chemical analysis, % dry mass basis.

Solid fuel	C	O	H	N	S	SiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Al_2O_3
KBC	48.86	6.56	3.05	0.80	0.73	23.09	2.15	0.34	0.31	0.16	0.15	13.80
CP	75.00	0.88	15.53	0.01	5.63	1.31	0.60	0.1	0.05	0.07	0.04	0.78

Notifications: KBC - Kuuchekinski bituminous coal, CP - Canadian petrocoke

Also the numerical and experimental investigation produced from Canadian oil sands petrocoke plasma gasification was fulfilled. Petrocoke is solid fuel consisting of fixed carbon, tar, and ash. The organic mass of the petrocoke was about 97% and the mineral mass was only 3%. Direct utilization of the petrocoke is difficult because of its low mechanical hardness and high tar content. A potential method to use petrocoke is plasma-steam gasification that converts the organic mass of the coke into high-calorific synthesis gas.

The received numerical and experimental data allowed comparing them and verifying the model, calculations are in satisfied agreement with experiments.

The fulfilled study of two essentially different in composition and in quality solid fuels plasma steam gasification showed the possibility to produce high quality syngas. The comparison between the calculated and experimental data showed satisfied agreement. The received syngas from the solid fuels is a high-quality power gas, and it can be used for synthesis of methanol and dimethyl ether. Syngas of this quality is a high reactive reducing agent for iron ore direct reducing and can serve as a substitute of metallurgical coke. Plasma steam gasification is a perspective method for hydrogen production through water steam decomposition by carbon of low-rank solid fuel.

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Alternative Solutions for MSW-To-Energy Processing

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Applied Plasma Technologies, McLean, USA

The US leads the industrialized world in municipal solid waste (MSW) generation, with each person generating on average 2.1 kg of waste per day and a total 251 million tons (2006).

Applied Plasma Technologies (APT) offers advanced oxygen plasma gasification technology with net power generation of about 1.3 MW per ton of MSW and electrical efficiency of MSW processing up to 70% in comparison with an achieved level of 35-37%. Each 250 TPD plant will generate up to 13MW of electrical power and export up to 325 MWh per day.

In case of all MSW processing net power output could be up to 326 million MW that could cover over 6% of the US power demand. Existing landfills recycling will give an additional 1 to 5%. The estimated program cost based on equipment ownership price is about $90 billion dollars.

The final product of MSW processing is electricity and heat in the form of steam and hot water.

The intermediate product is synthesis gas with high H_2 and CO content, which could be optionally used as an additional clean fuel for existing coal fired utility plants. This will lead to increased coal combustion efficiency, less pollution, involving renewable energy source, numerous environmental benefits, creation new jobs and so forth.

The major objectives of the proposed project are: (1) develop MSW processing plants with 250 to 500 metric tons per day capacity according to attached schematic; (2) integrate MWS plants with coal fired utility plants to increase their thermal efficiency and reduce pollution; (3) organize mass production of the MSW plants.

The project consists of three stages with a total duration of 83 months:

First stage – development and fabrication of a MSW processing pilot plant with 25 TPD capacity and field operation within 6 months. Duration 20 months.

Second stage – development and production of a full scale MSW plant with 250-300 TPD capacity with 6 months joint with utility plant operation. Duration 33 months.

Third stage – development and manufacturing of a 500 TPD plant pilot plant, starting mass production of the MSW processing plants with 25 to 500 TPD capacity. Duration 30 months.

The project would result in:

- Development of the MSW processing power plants product line with 25 to 500 TPD capacity;
- Optimization of the joint MSW and coal fired utility plants operation modes for better efficiency and less pollutions;
- Starting mass production of the MSW power plants;
- Worldwide marketing of advanced MSW processing technology and equipment.

Benefits of Solid State Technology in Modern Power Supplies

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Thermatool Corp., USA

Background: Thermatool started producing high frequency vacuum tube welders about 50 years ago and solid state, high frequency welders about 15 years ago. In those last 15 years Thermatool has produced high frequency welders from 100 kHz to 800 kHz and in power range from 50 kWatt to 1.4 mega Watts. Thermatool has come to dominate the tube and pipe manufacturing industry not just in the United States, but world wide. No one sells more solid state power supplies than Thermatool. We have developed this market dominance not solely because of our excellent product and service, but because we have real world process experience.

Thermatool started adapting our solid state power supplies for use in plasma applications about 10 years ago. During that time, a solid state power supply for use in a plasma application was developed to burn solid rocket fuel in Russia. Thermatool used a 200 kW, 400 kHz power supply to produce inductively coupled plasma used to concentrate radioactive material for Archimedes. Archimedes was a company in California that was working on a method of dealing with the radioactive waste from the Hanaford nuclear facility in Washington State. Thermatool has done numerous other plasma applications, including particled formation for nanomaterial development.

Thermatool is part of the Inductotherm Group, which consists of 40 companies that use high frequency, solid state power supplies in a wide variety of applications. These applications include melting metal, heating aluminum and copper billets for extrusion, heat treating and hardening of automotive and machine parts, producing single crystal steel blades for jet engines and a variety of other application. Thermatool has the unique opportunity to draw expertise from highly qualified engineers and scientists in all these different fields that Inductotherm has established dominance.

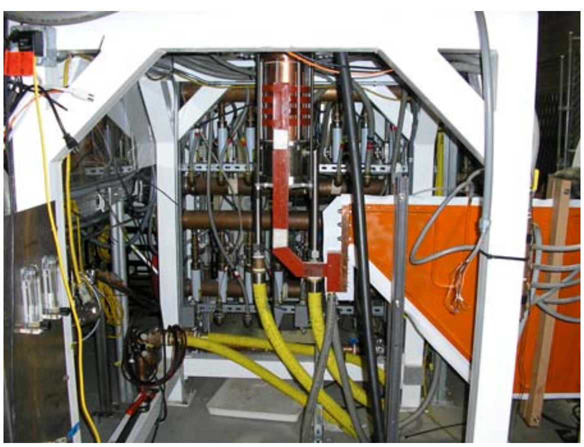

Fig.1. The plasma chamber, coil and RF generator

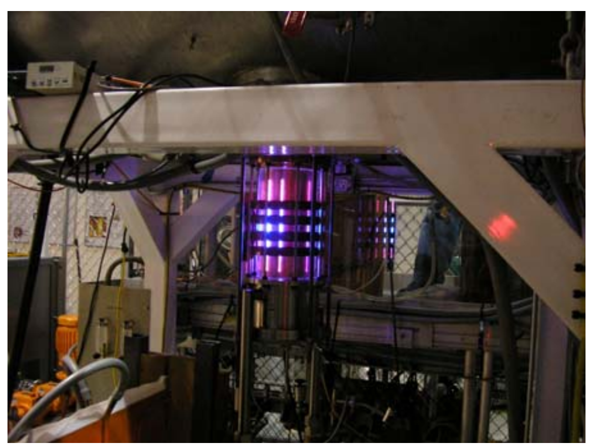

Fig.2. The Thermatool RF Generator lights the plasma torch

Perspective Plasma Technologies. Overview, Technical and Economical Advantages, Market Values

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Applied Plasma Technologies, McLean, USA

Recent progress in some directions of the plasma based technologies development allows to move them from dreaming to engineering and implementation modes. Among such technologies related to the field of our interest are the follows:

Plasma assisted combustion;
Coal gasification;
Waste processing;
Plasma aerodynamics.

Plasma assisted combustion can suggest plasma igniters for short term operation and plasma pilots for continuous operation within the pressure range 1-30 bar, electrical power 10W – 1.5kW, with or without additional fuel feeding into the igniter to increase its plume power up to several kW. These devices could provide high altitude aircraft turbine restarts, reliable ignition and flame control in scramjets, and flexi-fuel operation for all kinds of gas turbines. Non-thermal plasma in a form of spatial arc provides the most energy efficient solution for ignition and supports super-lean combustion. Plasma fuel nozzles combine several options, including multi-fuel atomizing, ignition at the point of fuel feeding, and continuous programmable flame control.

Coal gasification could be provided in the atmospheric pressure plasma reactors based on improved inductively coupled plasma torches (IC torches) with the solid state power supplies. Such a combination allows unlimited lifetime of both electrical and plasma generation modules, and high caloric value of syngas as a final product based on oxygen gasification process also based on recently developed air separation technology. The maximum achieved power consumption level per unit is 1.8MW and expected 10MW.

Waste processing is vital for many countries, but still not feasible for the majority of them due to high cost of ownership and operation expenses. Significant reduction of the operation costs could be achieved by application of improved IC torches with dramatically extended lifetimes, oxygen gasification and multi-feedstock operation modes to process any waste from scrap tires and MSW to coal and electronic waste. Possible integration of MSW modules with coal fired utility power plants will help reduce cost of the ownership and reduce pollutions. In case of all annually generated by the U.S.A. MSW processing net power output could be up to 326 million MW. That could cover over 6% of the U.S. power demand. Existing landfills recycling will give additional 1 to 5%. The estimated program cost based on equipment ownership price is about $90 billion dollars.

Plasma aerodynamics just celebrated its first decade anniversary. For commercial aviation it will help to convert the aircraft from mainly mechanically into electrically controlled systems with shorter response time, better volumetric and gravimetric parameters. Plasma will eliminate the external and internal shock waves in case of supersonic propulsion (cockpit, air intake manifolds, etc.); improve the aerodynamics due to plasma actuators application – will increase the lift force, provide the boundary layer flow control; reduce fuel consumption, and help to overcome existing ICAO limitations on cruise velocity for the passenger and business jets. This would mean the beginning of a new era in civil aviation.

Energy-Saving Electromagnetic Reactor for Mineral Materials Melting

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At present natural basalt, which is a product of ancient volcanic processes, became one of the main raw materials for mineral fiber producing. Industrial practice shows that basalt has great perspectives. A wide assortment of high quality plate heat insulators and mats is produced from basalt wool by its mechanical and chemical processing.

Almost all firms for basalt melting mainly use gas, coke and thermal-electric furnaces. But they are large dimension, resource-demanding and ecology negative. This is because of the branch of building materials is large-capacity production.

The compact industrial installation based on the efficient plasma electromagnetic reactor is offered (Fig. 1).

Fig. 1. Four electrode plasma reactor for minerals melting

The base of the installation for heat insulators production is electromagnetic reactor. The reactor is made of stainless steel in the form of water cooled sections. Four graphite electrodes are placed by the centre and the corners of equilateral triangle in parallel with axis of the reactor chamber. The working chamber of the reactor is enclosed into electromagnet with three poles. There are windings on the poles of electromagnet; they are inserted in a certain order, sequentially with power electrodes, and create magnetic field. The melt, produced in the reactor (Fig. 2), is mixing as a result of interaction between the electric current, existing between the electrodes, and the magnetic field of the three-phase electromagnet. It guaranties material heating rate acceleration, its more uniform heating and homogenizing of the melt.

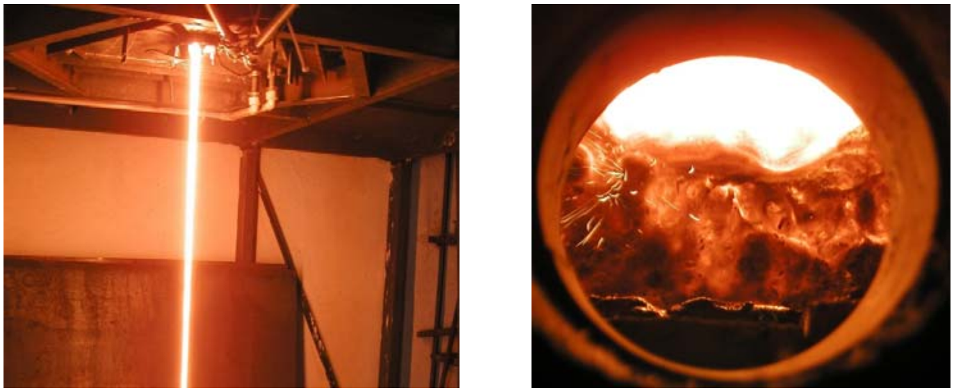

Fig. 2. The process of basalt melting (upwardly) and basalt flow from the reactor (underneath)

The melt from the reactor could be delivered either to a blowing device, or centrifuges for producing super thin fibers, and for manufacturing a number of new efficient heat insulating materials. It could also come to draw plates where the continuous fibers are being drawn; further, the roving is produced out of them. The melt could also be directed to metallic moulds and molding forms, where decorative goods, jewellery, monuments, and construction components for engineering industry are produced. External dimensions of the electrical reactor, including electromagnet, are ~1.5´1.5´1.5m. At the reactor productivity of 200-250 kg/h specific power consumption for basalt melt making came to ~0.9 kWh/kg. It is observed that the emission of gases polluting atmosphere is minimal. The power source is the adapted to the process three phase controlled thyristor converters. It is connected up to the power transformer having industrial frequency and voltage of 0.4 – 0.6 kV.

This three phase reactor with electromagnetic mixing of the melt could be used as waste vitrification reactor or glass-melting furnace. At that, in comparison with gas glass-melting furnace specific power consumption for the melt getting would decrease from 2.2 to 0.8-0.85 kWh/kg.

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Treatment of Contaminated Soil in Serbia Using Plasma Technology

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Occasionally in Serbia a rather large quantity of contaminated soil exits. One part has been caused by drilling and exploitation of crude oil borings. Already now there is more than 100.000 t of contaminated soil in a landfill. The second part presents contaminated sludge from water canals in Vojvodina (Northern part of Serbia). Several meters in depth the canals are full of sludge all together about 400.000 cubic meters with layers of several meters leaving only a half a meter of water. The third part of contaminated soil came from a lake near Belgrade.

Base on experience of use of plasma technology in Brazil for treating of soil contaminated with hydrocarbons and the experience of the company Retech (USA) and their plant in Switzerland (ZWILAG) for treating of dangerous waste with low level nuclear waste, we would like to develop use of such a technology in Serbia.

Our Institute not having possibility to invest in a device with plasma gas torch, has done experiments on treating dangerous waste (petrol contaminated soil, medical waste and electronic waste) with plasma from high voltage arc between graphite electrodes. Results of such treatment will be presented at the conference.

Using modern technology (thermovision, computer control and other) and software (LabVIEW and other packages), we are developing, by iterative methods, a very sophisticated control system which enables much more efficient functioning of high power plasma (furnaces) assisted combustion.

The classical regulated rectifier assembly has been used as furnace electrode main supply. Rectifier provides voltage 0 up to 100V with the current of up to 1000A.

For signal generation and data acquisition it was developed a measuring and control system based on PC Pentium 4. Beside PC, hardware consists of ADDA converter and external interface for analog signals conditioning. ADDA conversion is performed using commercially available converter NI 6251 from National Instruments. National Instruments M series high-speed multifunction data acquisition (DAQ) devices are optimized for superior accuracy at fast sampling rates. They have an onboard NI-PGIA2 amplifier designed for fast settling times and high scanning rates, ensuring 16-bit accuracy even when measuring all channels at maximum speeds. All high speed devices have a minimum of 16 analog inputs, 24 digital I/O lines, seven programmable input ranges, analog and digital triggering, and two counter/timers.

The software platform for predicted measurement methods was National Instruments LabVIEW 8.2 package, which is regarded as a high standard in the area of modern virtual instruments. LabVIEW is based on the principles of virtual instruments with the graphical user interface. Graphical user interface has two windows:

- *Front Panel* for process control and monitoring,
- Application diagram (*Block Diagram*) which presents used virtual instruments, relations between them, the course of signals and error detection.

In LabVIEW, one builds a user interface by using a set of tools and objects. The user interface is known as the front panel. One then add code using graphical representations of functions to control the front panel objects. The block diagram contains this code. We are developed all necessary applications.

Infrared thermography is a predictive maintenance technique that can be used to monitor the condition of plant machinery, structures and systems. It uses instrumentation designed to monitor the emission of infrared electromagnetic radiations to determine operating condition, by detecting thermal anomalies, for example areas that are hotter of colder than they should be. Computer based infrared camera, Wohler IK 21 has been used to determine and monitor the condition of energetic facilities and heat losses.

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Energy-Application of Non-equilibrium Arc Discharges for Activation and Modification of Reactive Atmospheres Used in Metal Heat Treatment Operations at 1 Atmosphere Pressure

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Recent economic trends force the multi-billion metal heat treatment (MHT) industry to reduce energy consumption, conserve reactive gas components of furnace atmosphere and minimize environmental footprint. In order to cost-effectively produce furnace atmospheres that are conducive to the main MHT processes, i.e. carburizing, nitriding, reduction annealing, etc., catalytic bed atmosphere generators such as endo-gas (O_2, H_2O and soot-free N_2-H_2-CO-hydrocarbon blends), exo-gas (N_2-H2-CO-CO_2), NH_3 dissociators and similar external systems are necessary.

These external systems show limited turn-down capabilities, high gas wastage rates, long startup and conditioning times, as well as extensive maintenance procedures. New technologies are sought to form the MHT furnace atmospheres "just-in-time", using reduced concentrations of reactive feed gases and attain high furnace temperatures only during processing of metal load. To date, this alternative approach hasn't been feasible due to the extended time-at-temperature required to "stabilize furnace", i.e. reach the thermodynamic equilibrium. It should be noted at this point that electrical plasma is a good candidate for "just-in-time" generation of reactive gas species even at lower furnace temperatures.

In contrast to the past methods of low-pressure (*ion*) plasma MHT, the current investigation deals with activating furnace atmospheres at atmospheric pressure and without direct contact of plasma with metal load. Our emphasis is focused on seeding reactive components into furnace volume rather than generating ionic components. Unlike the conventional combustion furnace atmospheres, MHT furnace atmospheres must be completely oxygen-free in order to avoid a highly detrimental intergranular oxidation of metal treated and facilitate diffusion of carbon (and/or nitrogen where applicable) atoms from the gas phase into the bulk of metal. To satisfy outlined requirements, a N_2 based blend with 3-10% of reactive gas addition, such as CH_4 (or NH_3), can be injected through and activated by a non-equilibrium arc plasma discharge generated inside and downstream of injection nozzle in order to form a new, improved type of rapidly reacting furnace atmosphere [1].

Saturation of MHT atmosphere with active carburizing and reducing species offers an important benefit in the case of atmospheric pressure furnace operations, namely, the neutralization of minute air leaks taking place in practice and wall-adsorbed oxidizing gases. Our concept and its carbon flux based applicability to various MHT situations is illustrated in Fig. 1 for two different batch furnace schedules: (1) carburizing metal parts starting with furnace at room temperature and (2) loading hot furnace with cold metal parts which results in a short-term temperature drop upsetting the conventional carburizing process.

Fig.2 illustrates experimental setup used in the current study. A non-equilibrium vortex plasma torch developed by Applied Plasma Technologies [2] was selected to test our concept in a laboratory scale box furnace (~1 ft^3). The torch operates in the transitional arc discharge regime (glow-to-arc or diffuse arc) wherein the voltage-current curve is "dropping": $V = A \cdot I^{-B}$, for a given flow rate of gas, while the voltage decreases with increase in current, *A* and *B* are constants for given flow rate, current and plasma setup. A laser gas analyzer (LGA, Atmospheric Recovery Inc.) was used to monitor the concentration of equilibrium species (such as N_2, H_2, C_mH_n, NH_3, CO, O_2, etc.) in the furnace, and a McPherson spectrometer for plasma gas temperature and relative concentration of stable and unstable gas species. The concentration of molecular hydrogen (H_2) was used to gauge the effectiveness (or selectivity) of the plasma discharge in the conversion of CH_4.

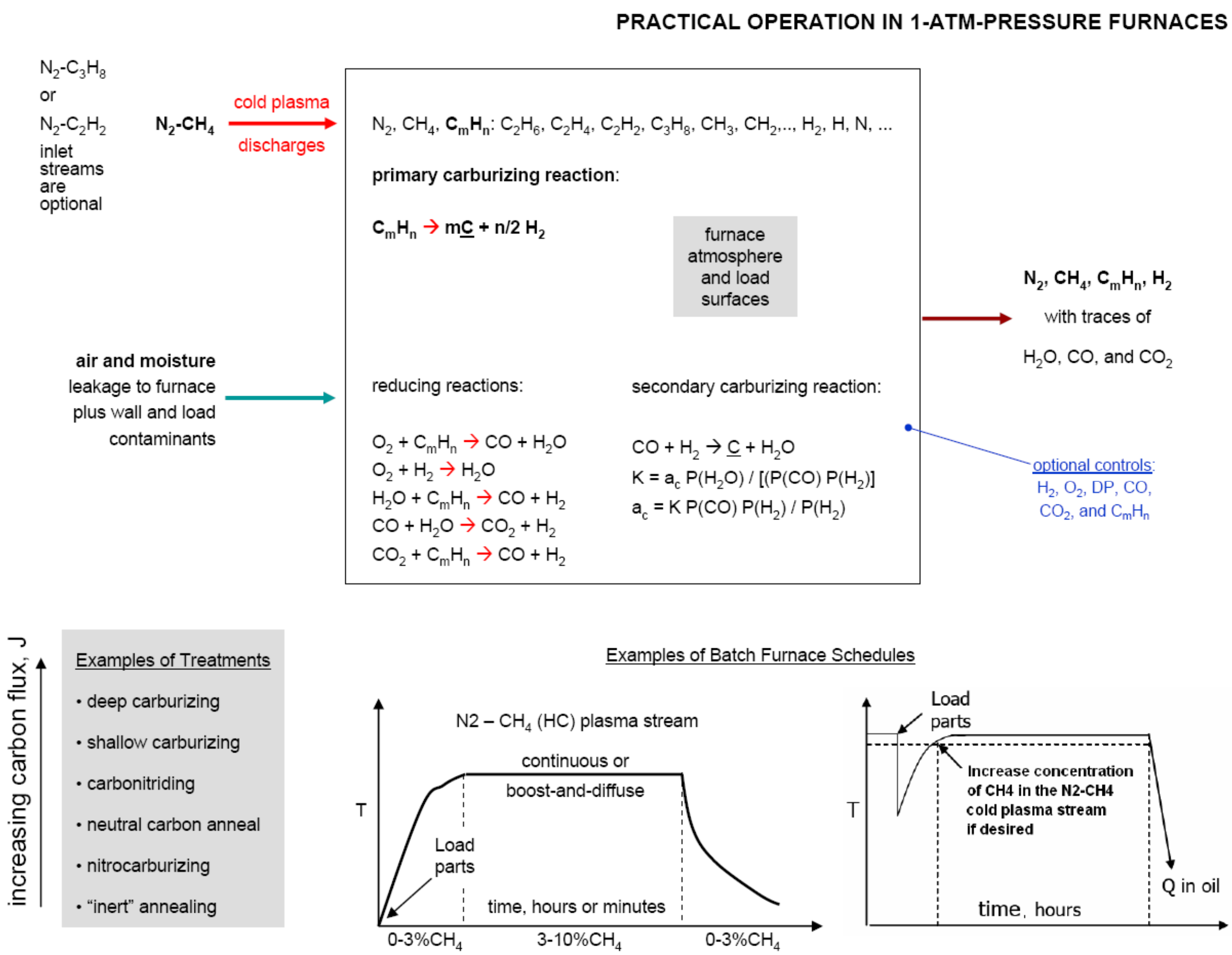

Fig. 1

In this paper, electrical characterization of the discharge and corresponding atmosphere diagnostic results will be presented along with the effects of changing independent system variables such as current, flow rate and furnace temperature on the atmospheric activation. The post-treatment surface characterization of metallic substrates will also be presented.

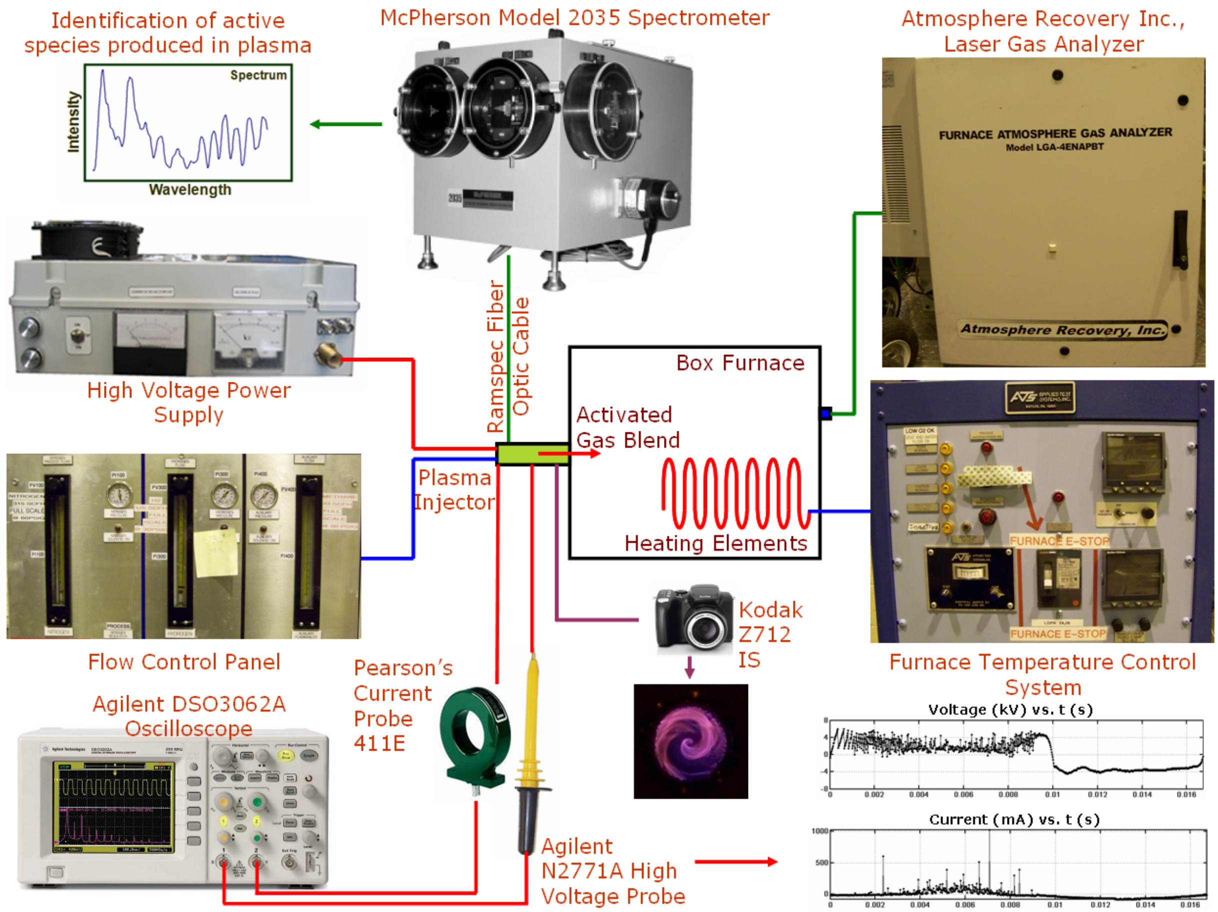

Fig. 2

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The list successfully commercialized, new technologies he conceptualized and developed includes rapid solidification of electronic-grade powders, methods for gas blanketing of liquid-phase metals, high-temperature burners for glass industry, arc-spraying of in-situ cermet coatings, cryogenic machining of metals and composites, and cryo-fluidic cooling of high-velocity oxy-fuel and thermal plasma sprayed coatings. His present interests focus on non-equilibrium plasma activation of carburizing and nitriding atmospheres for thermochemical metal treatments and kinetic metallization developed jointly with the Siberian Branch of the Russian Academy of Sciences in Novosibirsk. Member of TS and HT Societies of the ASM Int'l., he authored 35 technical publications and international conference presentations and over 76 patent references including 24 US patent families.

Shailesh Gangoli *graduated with a Bachelor's degree (B.E., 2002) in Mechanical Engineering from Manipal Institute of Technology, India. He then completed his Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) degrees in 2007 from Drexel University in Philadelphia, PA. During his graduate studies, he worked as a Research Fellow at the Drexel Plasma Institute. His primary area of interest and expertise lies in the design, experimental development, characterization and chemical kinetic/fluid modeling of atmospheric pressure non-equilibrium plasma systems for industrial applications. He has experience working with a variety of atmospheric and low pressure plasma-enhanced applications including ignition and combustion, reforming, surface treatment, air and surface sterilization, environmental cleaning, semiconductor processing and most recently generation of furnace atmospheres in metal heat treatment. He is presently employed as a Sr. Research Engineer at Air Products & Chemicals Inc., Allentown, PA.*

Treatment of Exhaust Gases from Industrial and Automotive Sources Using Non Thermal Plasmas

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For more than two decades, interest in gas-phase pollution control has greatly increased, arising from more attention to the health and economic effects of pollution, a greater respect for the environment, and a larger body of laws and regulations. Non-thermal plasma (NTP) technology shows promise for removing pollutants from gas streams and cleaning contaminated surfaces, using plasma-generated reactive species (e.g., free radicals). Such plasmas, where electrons are energetic (~ few eV) and the gas temperature is near ambient (~ 300 K), can generate both oxidative and reductive radicals - showing promise for treating a variety of pollutants, sometimes simultaneously decomposing multiple species. NTPs can also be used to 'activate or 'crack' hydrocarbon fuels, which promotes the combustion of the fuels (reducing unburned hydrocarbons and allowing fuel burning in regimes where the emissions of CO and NO_x are expected to be reduced; e.g., ultra-lean-burn conditions). In this paper, we will review selected experiments and field tests related to the cleaning of VOCs (volatile organic compounds) and NO_x from gas streams, using NTPs. In previous IWEPAC s, we have presented papers on experiments devoted to non-thermal plasma-assisted combustion, using model gaseous fuels (like methane, propane, and butane) and alluding to the possibility of applying the process to liquid fuels (like iso-octane, a gasoline surrogate), with such experiments demonstrating that NTPs can affect flame stability and, in this way potentially reduce the emission of pollutants.

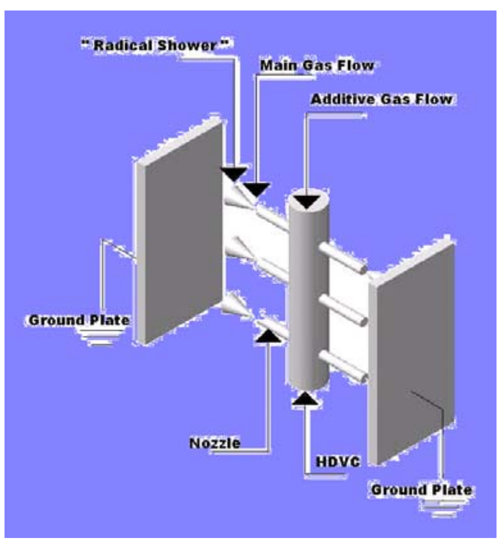

Fig. 1: Corona radical shower NTP system for NO_x treatment in flue gas

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He organized the 1st International Workshop on Plasma-Assisted Combustion in 2003, and co-organized the 2nd event in 2006..

Dr. Rosocha is now an independent consultant and his current R&D interests are focused on two of the most important problems of our time: CO_2 sequestration/global warming and national energy security (improving combustion, the efficiency of engines/fuels, and the conversion of trash into ‘green’ energy).

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Manuscript submission deadline **01-March-2009.**

Announcing a Special Issue of the IEEE Transactions on Plasma Science Plasma-Assisted Combustion (Scheduled for December 2009)

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 2009.

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 2007) 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 March 1, 2009** 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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