A NEW METHOD OF NANOCLUSTER COMBUSTION OF OFF-GRADE FUELS AND A BURNER MADE ON THIS PRINCIPLE

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1. INTRODUCTION

Usually high-grade fuels (gas, fuel oil, coking coal, gasoline, etc.) are used now in the world for the purposes of transport, industry, power engineering and other applications. The cost of these fuels at the market increases constantly, and this leads to unreasonably fast growth of tariffs on electricity and heat energy, metal-roll, building materials and other products [1]. Nevertheless, available abundant and large-tonnage off-grade fuels and combustible man-made wastes are not used widely. These almost “free of charge” fuels include: waste motor oils and lubricating fluids, pitches and contaminated fuel oils, not-utilized products of oil processing and water sludge of coal-preparation plants, and other combustible compounds. The main reason of their insufficiently wide application as the additional fuel resource is an absence of serial burners, which can efficiently and environmentally-friendly burn the above-mentioned “heavy” fuels. The demand for construction of the compact energy-saving autonomous heat generators, which meet the modern ecological standards, is topical now.

2. OPERATION PRINCIPLE OF A NEW-TYPE DEMONSTRATION BURNER AND ITS CHARACTERISTICS

The suggested autonomous burner is based on the original method of combustion of carbon-bearing liquid fuels. According to the patent of IT SB RAS [2], the feature of this device is separate supply of two flows into the combustion chamber: fuel+air and superheated water steam. The first demonstration version of burner with the power of about 5 kW on solar oil was made by engineer M.S. Vigriyanov. Then the program on investigation of physical-chemical foundations of such combustion was formulated. The following principle of ignition and burning of the off-grade combustible compound was postulated. The primary flame is formed at burning of “bad” carbon-bearing fuel under the conditions of partial or total blocking of air (oxidizer) supply. Finally, at the initial stage the aerosol soot flame with the given parameters of particles is formed in the combustion chamber. Then the secondary flame is formed by the pulse of superheated water steam, where water steam molecules decompose catalytically on the clusters of soot nanoparticles. This leads to organization of conditions required for efficient combustion of “heavy” fuels and maintenance of their stable burning.

The demonstration burner with the power of 20 kW was made on the basis of this principle (at this stage it was made on solar oil) (Fig. 1).

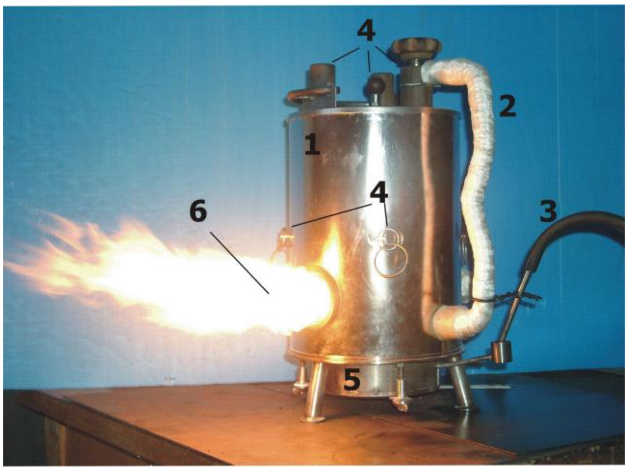

Fig 1. Demonstration burner of 10 kW power: 1 – case of two cylindrical shells, where steam generator is located; 2 – steam pipeline; 3 – fuel supply; 4 – units of burning regulation; 5 – lower part of combustion chamber; 6 – secondary flame.

3. EXPERIMENTS ON THE DEMONSTRATION BURNER ON COMBUSTION OF THE OFF-GRADE FUELS

The demonstration burner was tested on the special setup. This setup is equipped by the modern sensors and diagnostic systems for the flame and its ecological parameters. In particular, concentration of gas components were measured by the gas-analyzer "Autotest", the temperature field of the flame was measured by the thermocouple probe, the pressure, temperature and superheated steam temperature were measured by manometer and thermocouple of class XA, respectively. These experiments gave the following results.

The level of CO emissions in comparison with the indices of the burner with the same power produced by Weishaupt company (Germany) is 200 times lower, emissions of NO are lower by the factor of 18, and there is almost no soot at the burner outlet. Total autonomy of the burner (it does not require additional energy sources such as electricity, pneumatic energy, etc.) was achieved. There are no actuated and wearing parts. Auxiliary equipment (pump, compressor, automatics, etc.) is not required. In comparison with the burner of the German company "Falco-Ekkel" the developed demonstration burner works reliably under the conditions of bad weather (snow, rain, strong wind, etc.). Additional advantages of the developed burner with autonomous energy supply are as follows: it is not necessary to control visually, it is fire-safe, it can combust various off-grade fuels, it has low cost, long service life, and it is multifunctional.

There were also several test experiments on combustion of other off-grade fuels: waste motor oil, crude oil, water-coal fuel, and coal powder. The following results were obtained.

Waste motor oil caught fire, but this burning was unstable. In technical motor wastes there are many foreign admixtures, including metal ones. Moreover, water can be there because of cooling fluid penetration or because of some other reasons. Water spread over motor oil non-uniformly. Perhaps, due to the mentioned factors the process of burning is accompanied by considerable escape of black smoke and pungent smell. It is possible to separate water from oil and achieve more uniform oil consistence. But another problem arises: carbonization of metal walls of the burner. The coke column appears on the burner bottom fast (in our experiments it was formed during 15 min.). There was no outer flame, combustion occurred inside the burner. Coke deposits burnt during 5 min. with considerable escape of "grey" smoke.

The content of water in crude oil is significantly higher than in motor oil wastes, therefore, burning was even more unstable, but coking was slower; in our case it took about 30 min. The same problems appeared at combustion of water-anthracite fuel.

Final test results are shown in Table 1.

Table 1. Final technical characteristics of the demonstration burner

No.	Title	Parameter	Comments
1.	Type of fuel	Solar oil, motor wastes, water-coal fuel and other hydrocarbon off-grade fuels	Any grades
2.	Water	Preferably distilled	Water is actuating medium and component of burning
3.	Method of supply	Electrical heating, combustion of dry fuel	Combustion of more caloric, fast igniting fuel
4.	Time of supply	2-5 min	Depends on the temperature of ambient air
5.	Time of operation after one filling of fuel or water	Not longer than 10 hours	10 h (N = 5 kW) 3 h (N = 20 kW)
6.	Steam pressure	3-15 kg/cm^2	Working pressure of 6-7 kg/cm^2
7.	Additional kinds of energy	Not required	Autonomous device
8.	Auxiliary equipment (pumps, automatics)	Not required	Self-regulating device
9.	Actuated and wearing parts	Not available	Static scheme
10.	Service life	Not less than 50 thous. hours of continuous operation	Depends on material thermal stability of material
11.	Autonomy	Total	Start and operation under any weather conditions
12.	Sizes	Diameter of 175x370, fuel tank of 5l	For the power of 20 kW
13.	Mass (without filling)	7 kg	For the power of 20 kW
14.	Flame temperature	~ 1600 ^0C	For the power of 20 kW

Some difficult problems were revealed at combustion of the listed “heavy” fuels. Thus, at combustion of coal powder it is the necessity of sludge removal; at combustion of waste motor oil and crude oil it is wall carbonization; and at combustion of water-coal fuel it is the necessity to increase the time of stay of sprayed WCS in the combustion chamber.

According to obtained experimental results, the suggested new principle is suitable for all listed “heavy” fuels, but each of them requires construction completion of the inner burning unit and selection of specific operation parameters as well as individual tuning.

Unfortunately, the database on physical-chemical processes of combustion of off-grade fuels in the presence of high concentrations of H_2O molecules does not allow the new scientific approach to development of such burners, optimized by construction and operation parameters. Since in the given construction of burner the main medium, which brings the products of fuel pyrolysis to the zone of mixing with outer oxidizer (air) is water steam (under the pressure from 2 to 15 atm), it is necessary to solve the question about kinetics of water decomposition on clusters of formed soot. The following mathematical investigations in the field of water decomposition on surfaces of nanosize particles have shown that water decomposition on the surface of these particles can be efficient even at ~1000 ^oC, and not as in homogeneous case at ~2000 ^oC. Thus, kinetics of processes occurring with superheated steam and nanoparticles in the mixing zone of the burner requires consideration of heterogeneous processes on aerosol particles.

Catalytic processes, which can occur on nanosize soot and hydrocarbons particles, are of the particular interest. At this approach the main characteristics of products in the combustion zone shall be the function of nanoparticle size distribution, time of their formation, etc.

4. FUNDAMENTAL STUDIES OF SOOT-STEAM BURNING OF OFF-GRADE CARBON-BEARING FUELS

***Complex method for investigation of combustion processes*.** The two-phase soot-steam flame is the complex physical-chemical phenomenon, and it requires various research methods and devices. In our studies we have used a wide range of approaches. Specifically they can be divided into 4 categories: physical, optical, contact methods and computer calculations. The structure of applied methods is shown in Fig. 2.

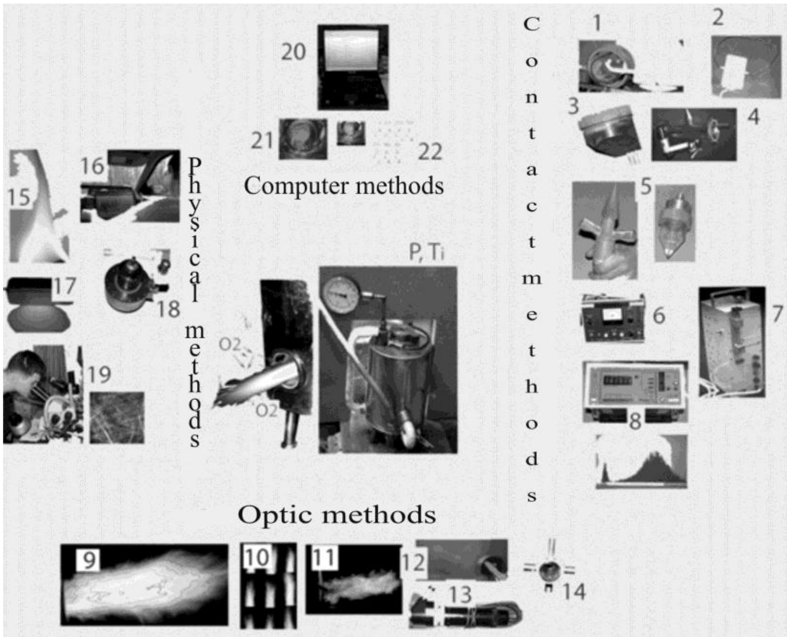

Fig. 2. The structure of applied methods for investigation of combustion processes

Contact methods: 1 – ceramic collectors - capillaries, 2 - pumps, 3, 4 – multiposition vacuum samplers for particles from 10 nm and 5 μm, 5 – inertial samplers for particles of up to 100 μm, 6 - nephelometer – of up to 10^9 particles/cm^3, 7 – fast condensation enlarger of clusters, 8 – aerosol counter and size spectrum of particles.

Optic methods: 9 – combined video recording with thermocouples, 10 – high-speed video recording of up to 4000 frames per second, 11 – recording with interference filters, 12 – laser scattering on aerosols, 13 – interference portable spectrometer with outlet to photoelectronic multiplier, 14 – time-of0flight nephelometer with resolution of 10^{-3} s.

Physical methods: 15 – generator of narrow jet of soot particles, 16 – portable set with mains supply of 12 V, 17 – UV lamp for model influence on water steam, 18 – high-sensitive fast barometric recorder, 19 – optic microscopy of high-temperature filters with particles.
Computer methods: 20 – portable set, 21 – handler for large (up to 10 HB) video files, 22 – special processing program for data array.

Detection of soot particles of nanometer size in the flame. Different types of soot particles taken from the flame combustion zone, shown in Fig. 3, were determined by different electron translucent microscopes (Institute of Cytology SB RAS, Institute of Geology SB RAS). According to electron-microscopic data, in the presence of “large particles” (parts of microns) in a volume we can always find the particles of fractal type, consisting of primary particles of the nanometer size. This is the first important result.

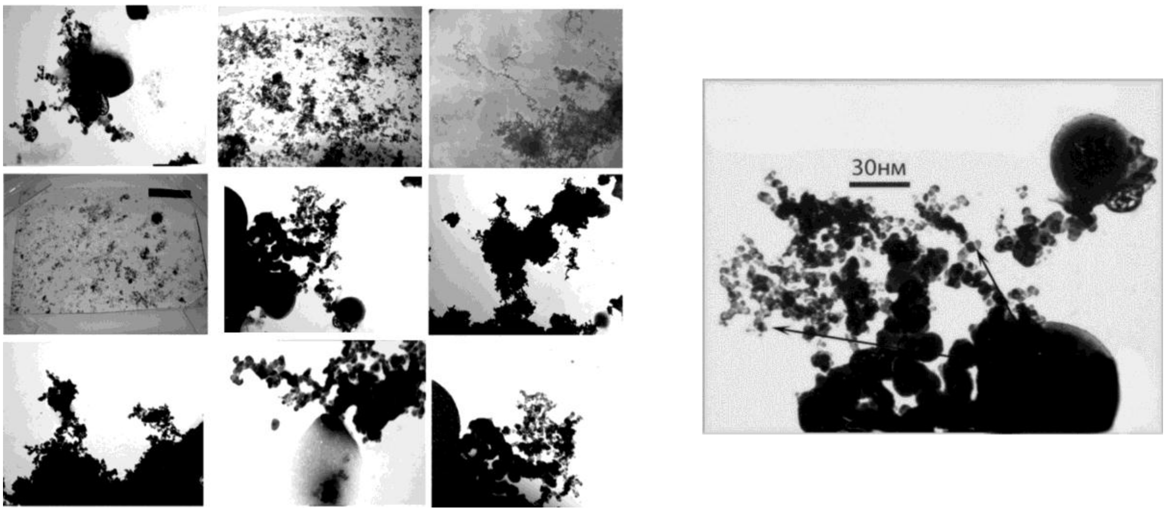

Fig. 3. Electronic-microscopic pictures of different types of soot particles.

Detection of OH radical in the ultraviolet range. According to the checked working hypothesis, nanoparticles can be the centers of increased catalytic activity of water steam decomposition with formation of chemically active OH radical. The indirect evidence of this idea can be glow of OH radical in the close UV range. Measurements of flame glow with application of interference filters are illustrated in Fig. 4. This is the second important result.

Pulsation burning of the soot-steam flame. Thermocouple measurements of temperature and luminosity of the same flame region have shown the presence of correlations (Fig.5).

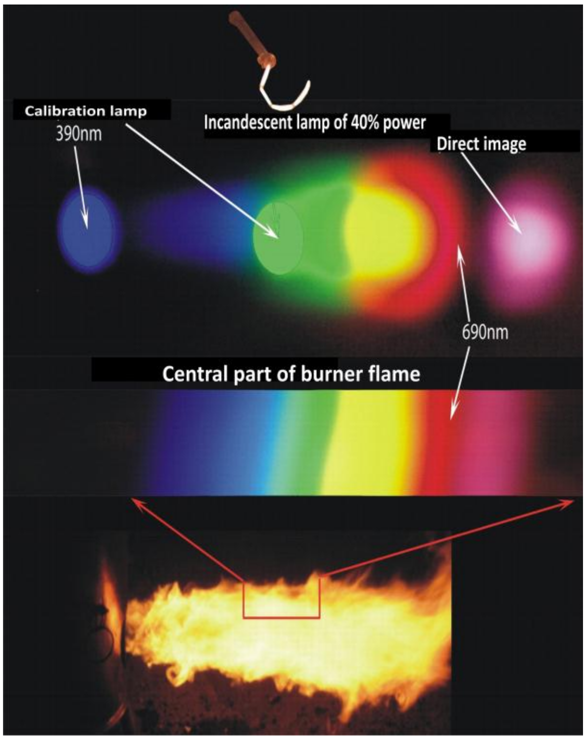

Fig. 4. Spectral measurements of flame glow with application of interference filters and optic prism block.

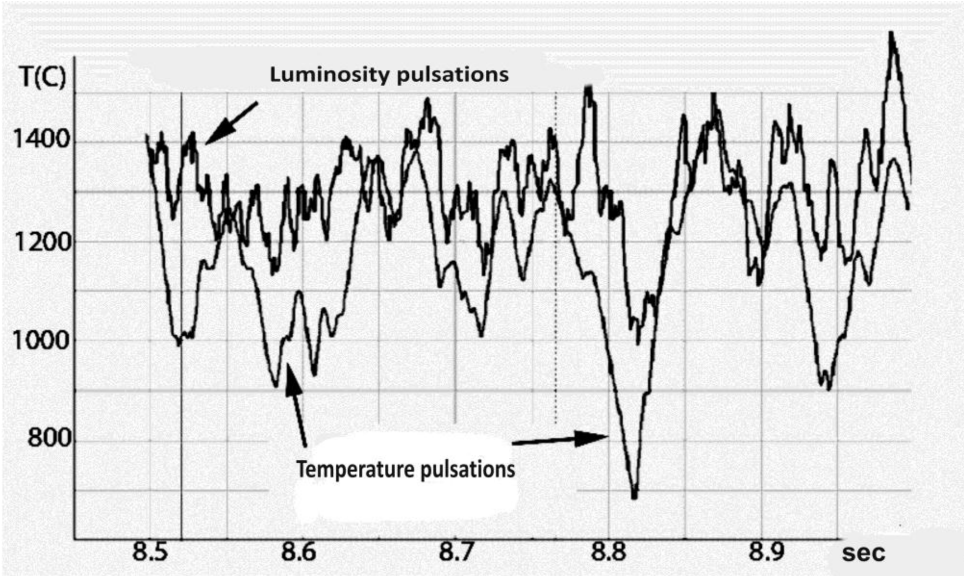

Fig. 5. Pulsation glow of the chosen flame region and thermocouple measurements of temperature pulsations in this region.

High-speed recording (by video camera Canon MV with frequency of 4000 frames per second) with big magnification of the mixing zone in the demonstration burner allowed us to observe some features of soot particle and outer oxidizer combustion in the presence of the steam phase (Fig. 6).

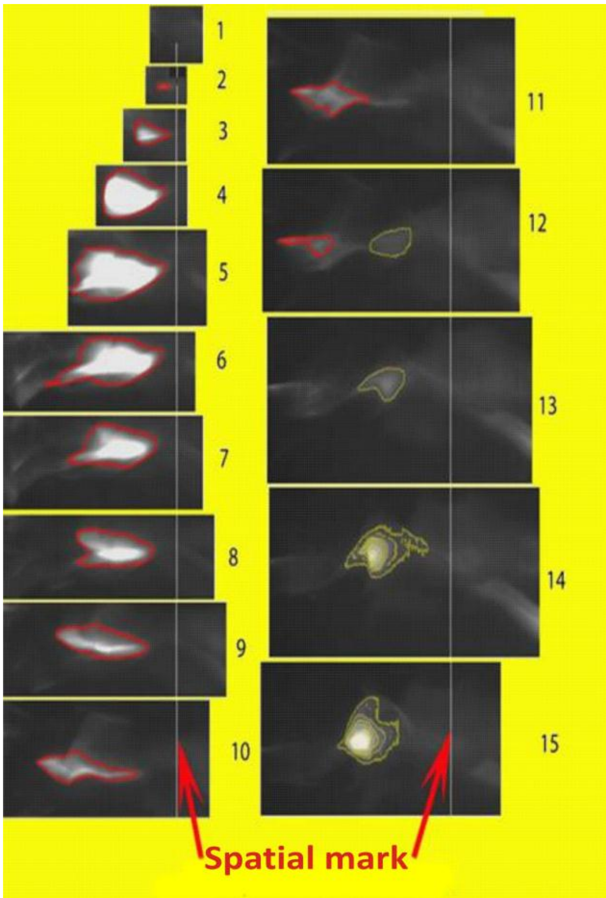

Fig. 6. Pulsation ignition and afterburning of aerosols at the boundary of steam jet and soot aerosol cloud.

Pulsation burning of the soot-steam flame can be also observed via the analysis of time scan of aerosols registered by the photoelectric counter of type “AZ-6” with forced fast pumping of air samples from the flame directly through its calculated volume. This is the third important result.

Spectrum of sound pulsations of the flame. Important information about the processes in the flame can be achieved through the new acoustic method. It is known that the sound analyzers are often used for investigation of operation features of different burners. On the basis of previous data about the pulsation character of ignition in soot-steam high-turbulent flame, obtained by high-speed recording, the following task was stated: to determine maximal frequencies in the sound spectrum as the reflection of these processes.

The sound receiving path from the flame jet consists of the microphone detector, ADC and line of computer registration. Linearity of signal transformation for the whole path is adjusted and calibrated with the help of sound generator. Basic harmonics are registered by the oscillograph and web-camera.

Measurement of the spectrum of flame sound pulsations allowed us to distinguish basic harmonics at frequencies of 800-1000 Hz under the conditions of optimal burning (Fig. 7). This agrees with measured video data of burning inside the flame within several millimeters. This is the fourth important result.

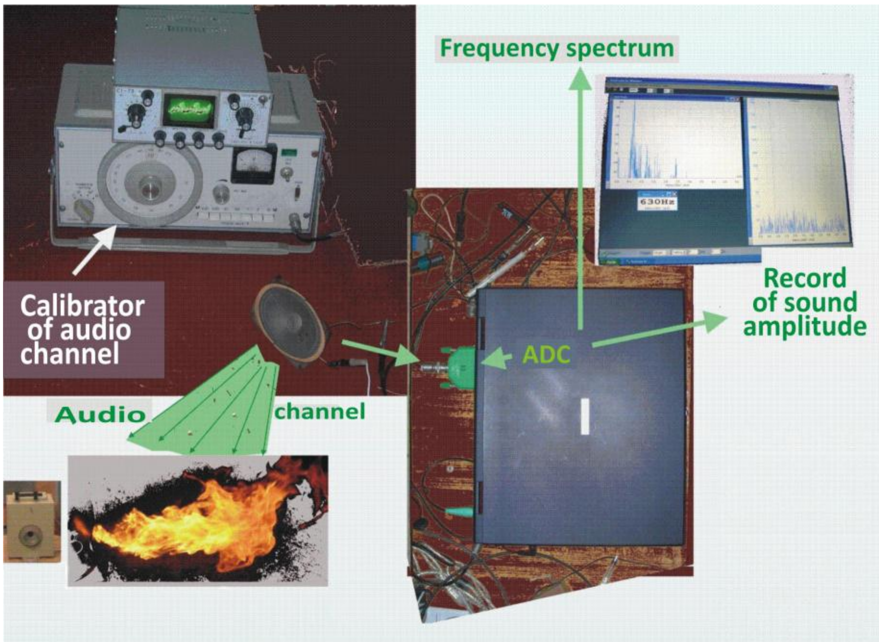

Fig. 7. Sound spectral analysis of the flame

CONCLUSION

Experiments on nanocluster combustion of such off-grade fuels as solar oil, water-coal fuel, waste motor products, crude oil, coal powder, etc., have been carried out. The performed test program has shown that the developed burner can be used for combustion of all listed "heavy" fuels, but each of them requires construction completion of the inner burner unit and selection of specific operation parameters as well as individual tuning.

The following has been determined by these experiments: presence of soot particles in the combustion flame of the nanometer range, decomposition of water molecules on soot nanoparticles with generation of chemically active OH radicals; pulsation burning of off-grade fuel; optimal sound frequency of qualitative combustion.

Application of optic spectroscopy in close UV and IR ranges and visible range of spectrum allowed us to obtain information about physical-chemical processes in flames of different scales with time resolution of not less than 10 ms and video framing of about 1 ms. Analysis of acoustic spectrum carried out in the range of high and low frequencies has revealed the features of microflash processes inside the flame and at the boundary of H_2O and solar oil mixing.

The obtained scientific and technical groundwork is the basis for development of the promising class of autonomous efficient and environmentally-responsible burners.

References

1. V.V. Salomatov. Nature-Consternating Technologies at Heat and Nuclear Power Plants - Novosibirsk, NSTU. –2006. – 853 p.

2. Patent of RF No. 2219435 "The method of soot-free combustion of fuel" Vigriyanov M.S., Salomatov V.V., Alekseenko S.V. of 20.12.2003.