

INFERIOR FUELS OIL SIMULATED COMBUSTION TESTING, AS EQUIVALENT NDT

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Abstract: Especially it is proposed a simulated combustion testing (SCT) for miniaturised inferior fuel oil (IFO) with exemplifications of advantageous validity verification at large boilers, as equivalent nondestructive testing (NDT) for industry. This type of testing can generate a new very profitable direction for the 16th World Conference on NDT activity. It is detailedly presented the industrial symbiotic technologies improvement, as the combustion of water-in-heavy fuel oil emulsions (WHFOE), and combustion of inferior fuel oil (IFO) with additived air (CAA), promoting energy efficiency and environmental pollution decrease. Beneficial optimization of these technologies only by industrial researches, at large boilers is an high expensive activity, having depends spectacularly decreased using the SCT. An item analysis was conducted on miniaturised samples of high fuel oil (HFO) droplets burned into the symmetry center of a simulator tubular minifurnace. The simulator was equipped with apparatuses for measurements and a conversion system of the burning droplet radiations into electric signals, together with an electronic computer for experimental data acquisition, processing, displaying and storing. The main beneficial findings of these measurements was to forecast the boiler industrial results, and the improvement of very efficient applications, by interpretation of the IFO radiation-combustion-ignition characteristics, experimentally obtained by simulators. The IFO negligible quantities which burn in simulator, by comparison with the great IFO boiler consumption, being nondestroyed samples in industrial testing, it justifies to consider the proposed SCT, as a NDT for industrial application.

1. Introduction: As inferior fuel oils are considered the heavy and low quality intermediate fuel oils. These fuels are especially produced by mixing in different proportions of the residues obtained from crude petroleum treatment (atmospherically distillation, vacuum distillation, thermal cracking, catalytically cracking... etc.) and light product. According to some specialists, the heavy fuel oils should have a viscosity higher than 3000 s. Red.1 and even more. It is considered that there is a wide range of intermediate fuel oils, starting with marine Diesel fuel and ending with the superior heavy fuel oil. Combustion of mixtures with water (20%-30%) in HFO particularly for obtaining the reduction of smoke containing soot emission is a well-known method but it is non-economically. Lately, this method was considerably improved, in order to high decrease the environmental pollution and deposits of solid particles on metallic heating surface of boilers, as well as to avoid the increase of the specific fuel consumption. First of all, it has been replaced the mixture, by high quality of WHFOE, but the water content in emulsion being drastic decreased. For this reason, according to the speciality literature [1,2], numerous beneficial advantages may be obtained by combustion of the WHFOE, with W limited to approximately 10%. Ampleness of the majority of beneficial effects are also essentially function of the operating and technical characteristics for the used power boiler, especially as follows: quality of used fuel, combustion air excess for different operation loads, type of boiler burners and heating surfaces, together with boiler wear. Combustion of the water-in-gas oil emulsions at Diesel engines has determined important reduction of exhausted polluting emissions of soot, CO, NO_x, as well as the fuel consumption diminution. Also for some Siemens-Martin furnaces, combustion of the WHFOE is applied with an important reduction of the environmental pollution by NO_x. According to the experimental results, using combustion with additived aerosols it is possible to obtain the following main advantages: saving of IFO consumption which increase the boiler thermal efficiency and intensification of combustion processes; reduction of pollutant emissions NO₂, CO, SO₃; decrease of the pollutant fine solid particles released in the form of soot and/or flying cenospheres; self-cleaning of heat transfer surfaces, the deposits of solid particles becoming easy friable, decreasing the maintenance dependences. CAA with activated aerosols of IFO for the ionisation of different boiler furnaces can give important advantages concerning depollution and boiler efficiency increase. For this reason, first of all it is necessary to know the optimum quality and quantity of additives becoming aerosols, which in fuel combustion air will be added. The most applied system for preparing the WHFOE uses special centrifugal pumps, working at high rotating speeds. Thus the HFO in previous mixed with water is inspired into the radial channels of pump rotor, where due the centrifugal forces, the water particles are removed into the very small space between rotor and pump carcass, so being cut in very fine particles. The system, operating with emulsion recirculation possibility, uses preheated HFO with the water inserted in precise amounts. This emulsifying installation works periodically and the resulting emulsion is stored in a main tank, where the burners are supplied from. The meaning of the appearance of advantageous effects when using EWHFO is related to the so-called secondary atomization. If the water fine particle size is of order about 2-5µm during the primary atomization process

obtained with mechanical pressure jet atomizer, these small water particles will be incorporated into the HFO droplets, the later having majority a magnitude order of 20-100 μ m. When the emulsion droplet enter into the incadescent combustions chamber they are heated up and sudden vaporisation of water particles occurs, leading to a further atomization of the droplets into smaller ones. The result is the secondary atomization, produced by micro-explosions, which appear as a consequence of the important vapour pressure increase inner the fine water particles from the EWHFO droplet. As a conclusion, very many constituents are released from the combustible mass of the HFO droplet. These components need a lower time to burn. The important decrease of the combustion time is mainly the result of the increase of the combustible mass surface area in contact with the atmospheric oxygen. For maximum reduction of soot and fly oil coke from exhausted combustion gases, using a small percent of water in HFO it is necessary the water to be uniform dispersed into very small particles. For this reason according some opinions would be sufficient $W \approx 3\%$ [1] in WHFOE, in side of 10-15%, but the valbility of this opinion depend also particularly of the HFO quality. Many authors consider that the fine water particles uniformly distributed in the oil, with a diameter larger than 6 μ m, have no advantageous effect on the combustion. Obtaining the double atomization, primary and secondary, constitutes the physical explanation to the beneficial development of the WHFOE combustion. Also the exhaust combustions gases of the emulsion burned droplet have a decreased or no soot or oil coke particles at all, depending on the emulsion quality. Will be distinguished by theoretical calculation, the effect on the gross thermal efficiency of a steam boiler, by adding the water mixed in HFO for a first variant, and water emulsified in HFO for the second variant. The boiler total consumption C_t of HFO (having mixed W) is the sum of three components [3]: C_m boiler consumption of the anhydrous heavy fuel oil (AHFO) necessary to obtain the useful heat H_u , C_w water consumption in the used HFO, and C_v consumption of AHFO which is utilized for water vaporisation, resulting:

$$C_t = H_u (\eta_m Q_m)^{-1} + 0.01 C_t W + 0.01 C_t W \Delta H Q_m^{-1} \dots \dots \dots (1)$$

where Q_m - lower heating value for AHFO; η_m - gross thermal efficiency for C_m fuel consumption; ΔH - heat consumed for heating and vaporisation of 1 kg water, after which follows superheating of water vapours till the boiler exhausted temperature.

After some transformations results:

$$\varphi = \frac{C_t}{C_m} = \frac{100}{(100 - W)(1 - \beta)} \Lambda \quad (2); \quad \Psi = \frac{C_v}{C_m} = \frac{\beta}{1 - \beta} \Lambda \quad (3); \quad \text{where } \beta = \frac{W}{1 - W} \frac{\Delta H}{Q_m} \Lambda \quad (4)$$

From (2), (3) and (4) result that increasing W , will increase the characteristics β , φ and Ψ i.e. also increase the consumptions C_v and C_t , which is a disadvantage. Thus for $W=10\%$ and a usual HFO, results $C_v C_m \approx 0.69\%$ and $C_t C_m \approx 1.12$. In real case using HFO, the boiler gross thermal efficiency has the decreasing value:

$$\eta_t = H_u C_t^{-1} Q_t^{-1} \dots \dots \dots (5) \quad \text{where } Q_t - \text{lower heating value}$$

for HFO. Using the above relations, after some transformations:

$$\eta_t = \eta_m \frac{C_m Q_m}{C_t Q_t} = (1 - \beta) \eta_m \dots \dots \dots (6) \quad \text{and} \quad \Delta \eta_t = \eta_m - \eta_t = \eta_m \beta \dots \dots \dots (7)$$

Combustion of EWHFO can take place at a combustion air excess smaller as HFO combustion and also smaller deposits of soot and oil coke on the boiler heating surfaces. Thus a large increase of boiler gross thermal efficiency at value η_e is obtained, and the difference $\Delta \eta_e = \eta_e - \eta_t$ may be determined by means of industrial measurements.

Laboratory results and discussions: 2. Combustion simulation of WHFOE. 2.1. Combustion testing method for WHFOE and HFO: The combustion testing method of WHFOE or HFO consist in the ignition and burning into a simulator incadescent combustion chamber, under standard conditions, of an WHFOE calibrated droplet. The radiation of burning droplet is received by a photocell, which transforms it into electrical signals. These experimentally obtained data by combustion simulation are acquired, processed and stored in the memory of a computer, then they are represented on computer display under the form of combustion oscillogram graphic heaving two courves. Operation principle of the combustion simulator is presented in Fig. 1.

Fig. 1 - Conversion system of the burning droplet radiation into electrical signals.(BDF - burning droplet flame; ICC - incandescent combustion chamber; LVR - light visible radiation; OET - optical electronic transducer; IRC - infrared camera; IR - infrared radiation; OS - optical system; DE - detector; CA - combustion air; CS - cooled screen; BD - burning droplet; - - - with ICC)

The standard conditions are mainly specified by the geometry of tubular combustion chamber; the initial temperature T_{fi} and pressure approximately equal to the atmospheric pressure inside the combustion chamber, the environmental temperature T_e and temperature T_o of an WHFOE or HFO droplet; system of supporting and inserting the emulsions droplet inside the incandescent combustion chamber; the air flow conditions around the droplet, mainly characterised by the value of Re air flow Reynolds number and the initial mean diameter d_o of combusted droplet. The combustion testing together with combustion development research of the WHFOE as well as and a HFO combusted with additived air, need the construction of a specific testing rig so called simulator consisting of the following main components [4]: an electric heated cylindrical combustion chamber, inside a metallic casing cooled by the water circulation generated by a pump; device for the propulsion of the emulsion droplet in suspension, on the extremity of a quartz filament which is pointing towards the interior of the combustion chamber; optical equipment for centering, processing, focusing on photocell and viewing the image of a burning droplet; electronic equipment consisting in a device for signalling the insertion of the droplet inside the combustion chamber, two photovoltaic transducers, amplifier and processor for the electric current signals, filter and parasitic radiation's compensatory devices; two electric heaters including annexes, the first for heating the tubular ceramic wall of the combustion chamber, made of four silica rods and the second one for preheating the combustion air, the latter having an automatic temperature regulating device; an electronic computer for experimental data acquisition processing displaying and storing together with the traced combustion oscillogram; syringe divider with specialized microscope and ocular-interpolating device for the precise droplet calibration at given dimensions. The main RCIC for a burned droplet of WHFOE or HFO result the interpretation of the combustion oscillogram, optained under the form of two curves represented in a rectangular system of co-ordinate axis. The τ time variation is represented in the abscissa and the I radiation intensity variation of the burning droplet is represented in the ordinate. According to the operation principle of simulator, radiation is tranformed into voltage (I) or electric power (Φ) by means of a photocell with amplification, which receives the light-near infrared radiations. Fig.2 shows the combustions oscillograms for two droplets of HFO and EWHFO which successively ignite and burn in the incandescent combustion chamber of simulator, but at the same initial standard conditions. The main RCIC for the fuel oils with cenosphere, as for example is HFO, are: selfignition delay time τ_i ; cenosphere ignition delay time $\Delta\tau$, when it is distinctly marked on combustion oscillogram; combustion time of cenosphere τ_c ; total combustion time $\tau_t = \tau_v + \tau_c$ existence time of droplet $\tau_e = \tau_i + \tau_v + \tau_c$; maximum radiation intensity of the droplet flame (produced by volatile matters combustion) I_v^m ; maximum radiation intensity of the burning cenosphere I_c^m ; droplet flame radiated energy, transformed by the photocell into electric energy E_v ; energy radiated by the burning cenosphere, transformed by the photocell into electric energy E_c . The functions I and Φ give integrated values for a spectral band $\lambda_1 - \lambda_2$ of the photocell absorbtion, so that:

$$\Phi = \int_{\lambda_1}^{\lambda_2} \Phi_{\lambda}(\lambda) d\lambda \dots \dots \dots (8) \quad \text{where } \Phi_{\lambda}(\lambda) \text{ is the radiant power for } \lambda \text{ wavelenght, having}$$

$\lambda_1 = 0.35 \mu\text{m}$ and $\lambda_2 = 1.3 \mu\text{m}$ for the used simulator photocell. Only if the sensibility of the photocell $\zeta = dI d\Phi^{-1}$ it is considered constant, results:

$$S_c = \zeta E_c = \zeta \int_0^{\tau_c - \Delta\tau} \Phi_c d\tau \dots\dots\dots(9) \quad \text{and} \quad S_v = \zeta E_v = \zeta \int_0^{\tau_v} \Phi_v d\tau \dots\dots\dots(10)$$

In this case E_c and E_v are represented at a certain scale, by the surfaces S_c, S_v between $I_c=f(\tau)$ and $I_v=f(\tau)$ curves and the abscissa axis. The selfignition delay τ_i is the time elapsed from droplet introduction in the combustion chamber till droplet ignition, which is produced at same time with flame appearance, marked on the Fig.2 by point A.

Fig. 2 - Combustion oscillograms of two droplets: with superior quality EWHFO (W=5%) and HFO, for $d_0=1.9$ mm, $T_{fi}=1023$ K, $T_e=T_o=292$ K, $Re=135$.

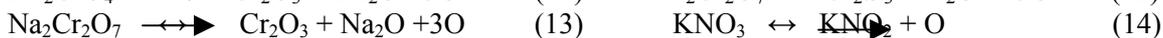
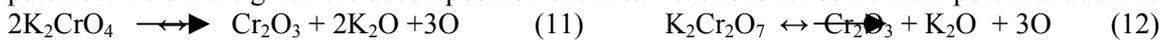
The combustion time of the volatile matters τ_v , is the time elapsed from droplet ignition (point A) till flame extinction (point B). Cenosphere ignition delay time $\Delta\tau$ is the time elapsed from flame extinction, till the visible ignition of the cenosphere (point C), marked by the appearance of its radiation in the visible spectrum. It must be mentioned that the chemical reactions of cenosphere ignition appear before the time marked by point C. The combustion time of cenosphere τ_c , was defined as a period of time elapsed between the flame extinction (point B) and cenosphere extinction (point D), which practically mark the end of droplet burning process. Quantities $\tau_i, \tau_v, \tau_c, I_v^m, I_c^m, E_v$ and E_c can be considered as the main RCIC for an HFO and in general for a IFO with cenosphere. Similar for an WHFOE these quantities become $\tau_{ie}, \tau_{ve}, \tau_{ce}, I_{ve}^m, I_{ce}^m, E_{ve}$ and E_{ce} . For a fuel oil minus cenosphere as for example are superior gas oils $\tau_c=0, I_c^m=0$ and $E_c=0$ thus missing $I_c=f(\tau)$ curve. In order to make a determination, on combustion simulator, the following steps are to be taken: creation of the d_0 initial mean diameter droplet desired and obtained at the extrimity of the siringe needle, through the controlled translation of a piston using a specialised screw mechanism; verification through direct measurement with a specialised interpolated microscope of the mean diameter d_0 ; to enter and store in the computer's memory the value of the parameters T_{fi}, T_e, T_o, d_0 , WHFOE density and appreciated maximal time of the combustion process development; insertion of the droplet inside the combustion chamber to be simultaneous with initiating data acquisition and storing system; ignition and combustion of the droplet; displaying of the combustion oscillogram on the computer's display; establishment of the τ_i, τ_v and τ_c times, which is done by exploring the combustion oscillogram; introducing into the computer's memory the processed and tabulated exeperimental results and the combustion oscillogram. Superposing of the combustion oscillogram for a tested HFO or an WHFOE and the standard HFO for which good industrial behaviour is known, can permite to establish some rapid improved industrial combustion procedure.

2.2. Optimum quality of WHFOE: The WHFOE quality is determined expensively and difficult, indirectly by determining the dimension and number of the water particules according their size and dispersion type in the HFO, with an electronic microscop, or directly significant expensive by analysing the effects of the industrial combustion of WHFOE. In Fig.2 are presented the combustion oscillograms for two droplets, the first one of HFO (specification RMF 25; ISO 8217/1997) and the second of WHFOE having water content W=5% with $d_0=1.9$ mm, which is ignited at $T_{fi}=1023$ K in conditions $T_e=T_o=292$ K and $Re = 135$. Because of the low content of cenosphere for the second droplet we

interpret that it was realised a good emulsion and this conclusion being verified by obtaining beneficial industrial results at power boilers. When we analyse by the preconised method the combustion of WHFOE droplets, two possible distinct cases may appear: the first case, when τ_{ce} , E_{ce} and I_{ce}^m are sensitively decreasing due the faster combustion of the cenosphere in comparison with the HFO combustion, the effect of secondary atomization being partially present; the second case when the secondary atomization is total, the whole droplet exploding due the cumulative micro-explosions, during or after the volatile matters combustion thus $\tau_{ce}=0$, $E_{ce}=0$ and $I_{ce}^m=0$. This second case is determining the optimal quality of WHFOE, and when it is burned, may lead to the achievement of maximal beneficial effects. The classification into the first or the second category depends on: principally of the emulsion quality, which, first of all by the emulsifying instalation type used and its working conditions; the natural disposition of HFO to permit obtaining of a very well emulsified water, which also determine the emulsion quality; the thermal conditions inside the furnace where the droplets combustion occurs, these conditions are favourable to intensifying the combustion at higher relative temperatures, but also may be favoured when are used low amounts of water in emulsion, three characteristics τ_{ce} , E_{ce} and I_{ce}^m , are the main new criteria for establishing the quality of an WHFOE. The research done allows the improvement of the emulsifying instalation in order to obtain the optimal operation regime.

3. Combustion simulation with additived air from aerosols. 3.1 Aerosol production and ionization mechanism:

For large energetic boiler it is comfortably to obtained aerosols using an additive electrolytic watery solution, which feed a small burner having atomization with low pressure preheated air. Thus the water of aerosols will be vaporized giving solid aerosols and the mixing between aerosols and water vapors will supply the general air-feeding canal of boiler burners. For relative small boilers, the operation principle of the aerosol generator equipments is based on the obtaining of aerosol particles in a tank partial filled with electrolytic watery solution that is passed through by a very low quantity of the burner combustion air. This air produce and transport fine particles, having average dimension $\sim 10\mu m$, towards the furnace of boiler, where first of all, the evaporated water dissociate in ions [2]. The aerosol particles result from explosion of very fine watery pellicle surrounding the air bubbles formed in watery solution, pass through the liquid separation surface in the tank air volume. Due the combustion heat release, the fine solid particles of additive becoming aerosols decompose and give atoms of free oxygen. A part of the formed ions is transported by thermophoresis towards the cold inner walls of boiler, where react with existent carbon in soot deposits on the furnace heat transfer surfaces, becoming easy friable deposits. At the bottom, in air with activated aerosols will be develop two ionization components, having advantageous effects. Thus the released free oxygen having negative charge determine the acceleration of approaching between O_2 and hydrocarbons, resulting a faster combustion reaction with a flame shorter as closer, and the molecular aerosols with negative charge acting on the chains of hydrocarbons favoring their breaking off and reducing the necessary combustion energy. The ionization effect propagates in the whole combustion chamber and taking into account of the temperature simultanelly increase, is obtained favorable conditions for complete combustion and decrease of environmental pollution. Especial when the IFO has an important mineral mass content it is possible as the formed deposits to adhere at the boiler heat transfer cold tubes, forming a solid crust very difficult to clean. In these cases it is necessary additional to complete the watery electrolytic solution with an additive for decreasing the melting-point temperature. The advantageous effects especially are function of: characteristics and percentage content of additive in electrolytic watery solution; rate between air with aerosols and total air for combustion; type of burned IFO and the length of boiler operation time with activated aerosols. An optimal additive is a mixing among different substances as bichromates and chromates of potassium or sodium, derivates of nitric acid ... etc. these mixtures being patented. Below are given the decomposition chemical reactions for some main potential additives:



These four reactions put in evidence the important quantities of released free atomic oxygen.

3.2. Conditions for optimization, new criteria: Using the same combustion testing method as in paragraph 2.1, for the case of combustion with additived aerosols we obtain the main RCIC, that is τ_{ia} , τ_{va} , τ_{ca} , I_{va}^m , I_{ca}^m , S_{va} and S_{ca} , where:

$$S_{ca} = \int_0^{\tau_v} I_{ca} d\tau = \int_0^{\tau_v} F_a(\tau) \quad (15) \quad \text{when exist } \Delta\tau_a, \text{ and } S_{va} = \int_0^{\tau_v} I_{va} d\tau = \int_0^{\tau_v} f_a(\tau) \quad (16)$$

The function I_a and Φ_a give integrated values for a spectral band $\lambda_1-\lambda_2$ of the photocell absorption. Only if the sensibility of the photocell $\zeta_a = dI_a / d\Phi_a^{-1}$ it is considered constant, results:

$$S_{ca} = \zeta_a E_{ca} = \zeta_a \int_0^{\tau_{ca}-\Delta\tau_a} \Phi_{ca} d\tau \quad (17) \quad \text{and} \quad S_{va} = \zeta_a E_{va} = \zeta_a \int_0^{\tau_v} \Phi_{va} d\tau \quad (18)$$

For the combustion without added aerosols the main RCIC are: τ_i , τ_v , τ_c , I_v^m , I_c^m , S_v and S_c . The functions S_c and S_v , with the same meaning as S_{ca} and S_{va} , result from similarly relations as (15), (16), (17) and (18). Effecting numerous experiments, resulted that for an industrial more efficient additive it is necessary to be simultaneously accomplish the conditions :

$$\tau_{ia} < \tau_i; \quad \tau_{va} \cong \tau_v; \quad \tau_{ca} \geq \tau_c; \quad I_{va}^m > I_v^m; \quad I_{ca}^m > I_c^m; \quad S_{va} > S_v; \quad S_{ca} > S_c \quad (19)$$

The inequality $\tau_{ia} < \tau_i$ is the result of concentration increase of free oxygen around the droplet and intensification of ignition reaction. The relation $\tau_{ca} \geq \tau_c$ is the consequence of two main factors: water content of liquid aerosols which decrease the combustion temperature and the rate of combustion for important carbons content of droplet cenosphere, which more completely and rapidly burned due the furnace ionization. When appear more solution the best solution correspond to the maximum values for I_{va}^m , I_{ca}^m , S_{ca} , S_{va} and minimum values for τ_{ca} , τ_{ia} , times.

These six magnitudes represent new scientifically criteria to select the variants of additivation, which will be supplied to the boiler, for the optimal solution established. Thus the experiment effectuated on simulator can improve the combustion with activated aerosols and much to reduce the expensive experimental industry depenses, for optimum boiler operation.

4. Industrial results: Will be presented as example some remarkable realizations. The power boilers of 330 t/h burning EWHFO [5] are once-through boilers, having intermediate superheating steam at 540 °C temperature and 13.7 MPa pressure, which initial were projected for combustion of natural gas sulphuros HFO. Also the power boiler has the inner shape of π , whith two combustion gases ducts and a rotary regenerative air heater. The boiler furnace whith a square section of 8.5 m x 8.5 m has four combination burner for natural gas and and HFO, with air admission in two stages (central air being swirl and peripheral air being as a straight jet). The EWHFO burner with nominal consumption of 3400 kg/h have a spill pressure-jet atomizer with whirling chamber and emulsion suply under an excessive pressure of 3.5 MPa. This burner is the same as HFO variant, but having the nominal consumption diminished at 3100 kg/h owing to the emulsifying water absence. Testings were developed at boiler thermal load (BTL) between 60% and 94%, using EWHFO with water content $W=7.7-10.8\%$ ⁵. For example, operating at BTL of 85% the critical combustion air excess coefficient $\alpha_c=1.025-1.04$, is obtained at boiler furnace exhaust with the maximum loss by incomplete combustion $q_{3max}=0.25\%$. The coeficient α_c decrease in the same time with the W decreasing till $W \geq 9.6\%$ but after this value, α_c became practicaly constant. For a long time exploitation of power boiler, the combustion air excess coefficient is greater as α_c with about 0.05 obtaining for Bacharach index the values 0-1 and $q_{3max} \leq 0.1\%$. During the tests, was established that even a viscosity of 6 °E for EWHFO permitted an eficient industrial combustion. The boiler gross efficiently had values of 92.6-9.35% with a relative constant value till $W \geq 9.5\%$ and after this value it decrease. Don't obtain an influence of W variation in mentioned limites, on the NO_x content in waste gases which had admissible values but decreasing in the same time with boiler load decrease. So at the boiler thermal load of 85%, combustion of high quality EWHFO having viscosity 2.5-3.5 °E, for $\alpha_c=1.025-1.040$ with furnace mean temperature $T_f=1723-1734$ K resulted $NO_x=350-364$ mg/m³_N (corrected for O₂=3%). As a result of thermal test was established that for a long time boiler exploitation, combustion of EWHFO with $W=8.5 \pm 1$ give a: certainly and economical operation with the increase of boiler gross thermal efficiency of minimum 1.5; deposit diminution of soot and oil coke particles in the convective heating surfaces and high depollution of the environment due unburned solid particles, carried off from the combustion zone by flue gases; important increase of operation time between two boiler stoppings the for cleaning of convective heating surfaces or interior washing; suplimentary depollution owing to the use for EWHFO of waste water usually discharged in drainage channels or in effluents. On the base of optimization of the quality and quantity of additive for aerosols, were effected industrial applications on different types of boilers using appropriate technologies as ACOM and PIR. The PIR technology conceived in Romania [5] was applied to relative small boilers for example with thermal power 5-12MW and to large boiler for example the energetic boiler of 530MW electric power. The advantageous effects, which were mentioned in the second paragraph, are more sensible with this new technology after a boiler operation activity of 700 – 1200 hours. The first main demonstrative application

was at a power boiler of 420 t/h steam with 137 bar pressure and 540°C temperature, having natural circulation. This boiler was equipped with 18 residual heavy fuel oil burners having mechanical pressure jet atomizers, the sulfur content in fuel being 0.6 – 0.8 %. Were used numerous aerosols generators what obtained the additive aerosols particles on an electrolytic watery solution which is passed through by a very low quantity of the total combustion air for burners. This air containing aerosol particles, in canal of total combustion air for burners is introduced, realizing with total air a homogenous mixing. Every aerosol generator had the main component a watery solution tank. For two boiler operation time periods of 27 days without combustion activation and 52 days using combustion with aerosols, research experiments were effected. In the first period of time the boiler steam output gradually decreased between 380 t/h and 300 t/h and the pressure losses Δp of the flue gases on the second boiler section, increased between 1750 Pa and 2570 Pa due the formed deposits of soot, flying coke and ash. For the second period of 52 days the decreasing of boiler steam output was between 380 t/h and 320 t/h, but the increasing of Δp was between 1800 Pa and 2550 Pa, emphasizing the great efficiency of PIR watery solution. In this case the combustion with activated aerosols gives also other important advantages: increase of the thermal efficiency in average with about 1.5%, especially due the reduction of solid fine particle deposits on the heat transfer surfaces, which become easy friable determining the increase of useful heat transfer; important decrease of pollution due emission of solid particles. Thus at boiler steam output of ~ 350 t/h, the concentration of solid particles in the exhaust combustion gases (corrected at $O_2 = 3\%$) was decreased with 40.2 mg/m³_N (that is with about 52%), and the decrease of unburned carbon in soot + flying coke was of 33.9% coming up to 8.9%; sensible decrease of maintenance depenses and pressure losses on the combustion gas way through the boiler; decrease of NO_x concentration in exhaust combustion gases, as for example at 85% of the boiler load the average decrease was from 472 mg/m³_N till 430 mg/m³_N; decrease of the depression in the second section of boiler due the reduction of adherent solid particle deposits, which determined the decrease of the environment air aspiration inner the boiler and thus resulted the reduction of excess air from exhausted combustion gases, with about 20%; Another demonstrative application with similar advantageous results was realized at a power boiler of 525 t/h steam having 139 bar pressure and 540°C temperature with natural circulation and intermediate superheating. The boiler was equipped with 12 residual heavy fuel oil burners having also mechanical pressure jet atomizers, the sulfur content in fuel 2.5 ÷ 3.5. In spite of good obtained results is recommended to change the aerosol generator system. Thus for steam boilers over 100 t/h and water boilers over 50 Gcal/h is more efficient to obtain aerosol using additive electrolytic watery solution which feed a small burner having atomization with low pressure preheated air.

Using the proposed combustion testing method together with the realised combustion simulator, it is possible also to be carried out other type of very economical applications and efficient new complex research activities, as follows: the determination of RCIC for different FO at producers (expecially crude oil distilleries) for accurate control and optimum directing of tehnological processes, the result being high quality petroleum products, and improved industrial combustion; the determination of fuel oil RCIC at buyers, enabling them to set out the necessary adjustments and mixing procedures at industrial burners and Diesel engines, for an optimum operation; the determination of RCIC for diferent FO at distributors (pumping plants in harbours for ships, units for correct cleaning treatment of heavy or intermediate fuel oils which supply different beneficiaries); the elaboration with minimum expenses, of the quality and quantity of additives that must be added to different FO, in order to improve their ignition, respectively combustion characteristics, thus much reducing the expensive industrial experiments carried out directly on power boilers, Diesel engines...etc; the setting down by means of much limited research, of the industrial efficient use possibilities of same non conventional fuels, as vegetable oils, fuel oils produced by means of coal and different type of liquid ecological fuels; the establish with minimum expenses the efficient combustion equipment of liquid combustible wastes, as residual methanol for example; the avoidance of the possibly disastrous effects of the phenomenon of mixing incompatibility between HFO and gas oils or other relatively high petroleum products in order to obtain improved intermediate fuel oils for Diesel engines; the rapid determination of electroisolating oil ignition characteristic τ_i thus giving up the existing tiresome and non accurate methods (the determination of the oxidation induction periond and of the inflammability point) leading to the avoidance of the selfignition of these oils in the tranforming station by means of their replacement in due time; the carrying out of deep investigation in fuel oil combustion stucture, the initially possible results being the discovery of same new phenomenological details which can contribute to the optimisation of combustion chambers, and elaboration of nonconventional methods for improvement of combustion depollution tehniques. A new branch of the

combustion science so called “Combustion Graphology of Fuel Oils” was developed [4]. Thermography of flame and cenosphere of the burning droplet using an infrared camera inside of the simulator optical electronic transducer, with a similar operation principle, gave new supplementary technical and scientific data on combustion process development according to the measured apparent temperatures from the infrared thermogrammes; the combustion simulation of solid fuel particles using the presented method, to determine and compare the RCIC of different coal types, may be effected on the adapted same simulator with industrial beneficial results and opening a large field of important scientific achievements.

6. Conclusions: Due of the inferior fuels oil negligible quantities as droplets which burn in simulator, by comparison with the great IFO boiler consumption and the great decrease of industrial experiment, being nondestroyed samples in industrial testing, it justifies to consider the proposed simulated combustion testing, as generating a nondestructive testing for industrial applications. General speaking, from the paper results that there are two variants of equivalent NDT: The first one which give the solution only by laboratory experiments in simulator burning of infimes quantities of fuels as small droplets. The second variant, also by burning in simulator small fuel oil droplets, respecting the conditions of the equation (19) for CAA, and the conditions $\tau_{ce}=0$, $E_{ce}=0$ and $I_{ce}^m=0$ for the combustion of WHFOE, to obtain the optimal solution solution in industrial applications but saving much fuel by avoidance many expensive industrial experiments. A similar method for miniaturized combustion testing and research, can be used efficient also for others fuel oils with large utility, as for example are different intermediate and gas oils, increasing the technic and scientific importance of preconized solution. For this reason and according to the very profitable applications, this type of testing can give a new very efficient direction for the 16th World Conference on NDT activity.

Nomenclatures: FO – fuel oil(s); HFO – heavy fuel oil; BTL – boiler thermal load; IFO – inferior fuel oil; ACOM, PIR – technologies for combustion with additived aerosols; AHFO – anhydrous heavy fuel oil (HFO minus water content); WHFOE – water-in-heavy fuel oil emulsion(s); RCIC – radiation-combustion-ignition characteristics; e – index denoting the notation is referring to an WHFOE; a – index for combustion with additived aerosols; m – index for maximum value of characteristics; W – water content in HFO, mixed or emulsified [%]; C_w – water consumption, [kg/h]; C_t – boiler total consumption of HFO (mixed with water), [kg/h]; C_m – boiler consumption of AHFO, [kg/h]; C_v – consumption of AHFO utilized for water vaporisation, [kg/h]; H_u – boiler useful heat at the consumption C_m [kJ/kg]; ΔH – heat consumption for heating – vaporisation of 1 kg water, and superheating of resulted vapours till the boiler exhausted temperature, [kJ/kg]; Q_m – lower heating value of the AHFO, [kJ/kg]; Q_t – lower heating value of the HFO, [kJ/kg]; η_t – gross thermal efficiency for the consumption C_t ; η_m – gross thermal efficiency for the consumption C_m ; η_e – gross thermal efficiency for WHFOE consumption; I – radiation intensity variations of the burning droplet, transformed into voltage [mV] or into power [mW]; I_v^m , I_c^m - maximum radiations intensity of the droplet flame and burning cenosphere, [mV]; τ - time variations, [ms]; τ_i – selfignition delay time, [ms]; τ_v – combustion time of volatile matters, [ms]; $\Delta\tau$ - cenosphere ignition delay, [ms]; τ_c – combustion time of cenosphere, [ms]; d_o – initial mean diameter of the combusted droplet, [mm]; T_{fi} – initial [K]; T_o – temperature of the WHFOE or FO [K]; Re – Reynolds number of air flow around the droplet; λ - wavelength, [μ m]; E_v , E_c – energies radiated by the flame or cenosphere of the burning droplet, transformed by photocell into electric energy, [mJ]

References:

1. A. Sjogren, Burning of water in oil emulsion, Tehnological Institute, Copenhaga, Denmark, p. 297-305, 1987.
2. V.V. Ghia, Combustion depolution applying primary modern technologies. Scientific session of environment engineering, Politehnic University of Bucharest, Romania, vol. II, p. 91-96, 2000.
3. V.D. Iosufova and others, Otenka vliania sjiganiia vodomazutnoi emulsii na rashod topliva i K.P.D. parogeneratorov. IZVUZ, Energetika, nr. 9, p. 92-95, 1984.
4. V.V. Ghia, Efficient application of a combustion testing graphologic method for fuel oils. proceedings of the 5th AITA, p.41-48 Venezia, 1999. Printed by CNRS, Italy, december 20.
5. M. Radulescu, Technologies for combustion process improvement of heavy fuel oils. Energetica, 47, nr. 1, p. 8-13 and nr.7, p. 297-308, Bucharest, Romania, 1999

