P a r t 4

COMPLEX TECHNOLOGIES OF REDUCTION OF ENVIRONMENTAL POLLUTION FROM THERMAL POWER PLANTS

4.1. Combustion of water-oil emulsion in steam boilers

4.1.3. Water emulsion formation based on crude oil and its combustion in DKVR-10/13 boilers

V.I. Kormilitsyn, O.V. Shmyrkov, N.B. Yushkov, Branch of the Federal budget - funded research Institute of Machines Science named after A.A. Blagonravov of the Russian Academy of Sciences, Research Center for Nonlinear Wave Mechanics and Technology RAS, Moscow, Russia

ABSTRACT

Experiments on formation of water-fuel emulsions from crude oil and fuel oil, as well as industrial testing of a technology of preparation and combustion of water-fuel emulsions were performed. It is demonstrated that this leads to improved efficiency and reliability of power equipment.

KEYWORDS

Oil, fuel oil, water-fuel emulsion, steam boiler, efficiency, reliability.

Development of representations about oil and oil products as about oil disperse systems [1] is accompanied by expansion of applying the methods for intensification of heat and mass transfer processes for their treatment.

In heat power engineering preparation of liquid hydrocarbon fuels in the form of water-fuel emulsions with their subsequent combustion in boiler furnaces showed a number of advantages with regard to ecological and techno-economic aspects. This was the beginning of their widespread introduction in practice of operating fuel handling equipment of boiler plants [2,3].

A wide range of initial boundary conditions, as by composition of the initial fuel components, and as their final qualitative (physicochemical, thermal, etc.) characteristics, makes a significant effect on efficiency, environmental friendliness and reliability of power equipment operation and maintains relevance of this problem for the present.

One of the ways for further solution to this problem is the intensification of physical impact on the initial environment of the product by wave technology [4] and its cavitation treatment [5,6]. In [3] some energy and environmental aspects of the influence of wave impact on the water-oil emulsion properties is considered. It was shown that preparation of fine emulsions improves the fuel combustion efficiency and provides more complete combustion in comparison with the original fuel. It is thus noticed improving the hydrocarbon fuel quality (decrease in viscosity, increase in the output proportion of light oil products) due to the use of a multifactor impact [7]. Improvement of technologies of more deep oil refining leads to deterioration of a number of physical and chemical properties of the final product (fuel oil), that requires a corresponding adjustment in technology of fuel handling equipment of boiler plants and heat power plants.

Preparation of water-oil emulsions with water particles (of 1-5 microns), uniformly distributed over the fuel volume allows to realize almost complete fuel combustion (with zero values, or with traces of chemical and mechanical fuel underburning), with high technical-economic performance of the power equipment operation (reduction of critical values of excess air ratio). It also allows to increase its reliability under conditions of industrial equipment operation and reduce air, water and soil pollution.

Abatement of air pollution is due to the reducing the toxicity of flue gases by 7-30% depending on the initial state of the furnace-burner devices as well as operation and technological factors of fuel combustion. In addition to NOx emissions reduction, multiple (from 2 to 10 times) decrease in benz(a)pyrene concentrations in flue gases is achieved ($C_{20}H_{12}$ – is an indicator of carcinogenic substances in fuel combustion products and is the root cause of human cancer disease). Through the use of oil-contaminated wastewaters being the additive to water emulsion, a problem of creating zero-discharge fuel facilities of boilers and TPPs is resolved, and thus their energy utilization is realized [8].

Composite fuel with special additives in the fuel mass results in effective neutralization of sulfur compounds, being the source of environmental pollution, as well as having a negative impact on the state of power equipment with regard to formation of low-temperature sulfuric-acidic corrosion.

Applying the technology of composite water-fuel emulsion preparation allows to proceed to the fuel combustion implementation processes with extremely low excess air ratio. In addition to reduced power consumption for forced-draft installations, it helps to improve the environmental situation (decrease in atmospheric air consumption, smaller release of flue gases into the atmosphere and reduction in their toxicity).

The proposed fuel preparation technology allows to create a zero-discharge fuel handling facilities, i.e. to exclude fuel losses when draining the settled water from fuel tanks, to waive or significantly reduce the expenses for expensive equipment of treatment facilities.

To form water-fuel emulsions based on hydrocarbon fuel, flow-wave generator of flat type is applied. Its schematic diagram is shown in Fig. 1.

Parametric experimental studies of the influence of hydrodynamic characteristics of the generator operation on the intensity of cavitation effecting the liquid flow with a quality product definition were conducted a wide range [9]. Amplitude-frequency characteristics of pressure fluctuations followed behind the first streamlined body were obtained. They showed that in this place under certain modes the pressure peaks arise (Fig.2); the peaks are associated with the quasi-stationary nature of flow separation from the streamlined body [10].

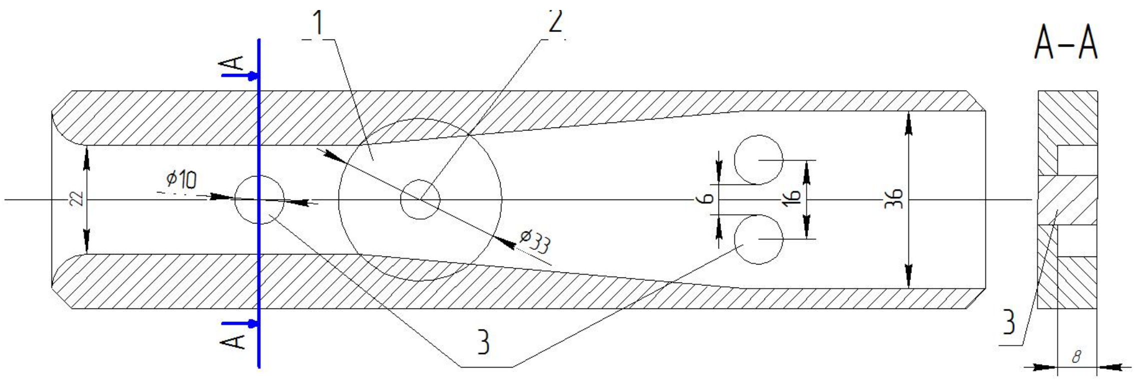


Fig.1. **Schematic diagram of the channel:** 1 – fitting position of control lead insertion; 2 – fitting position of piezoelectric pressure sensor; 3 – streamlined body.

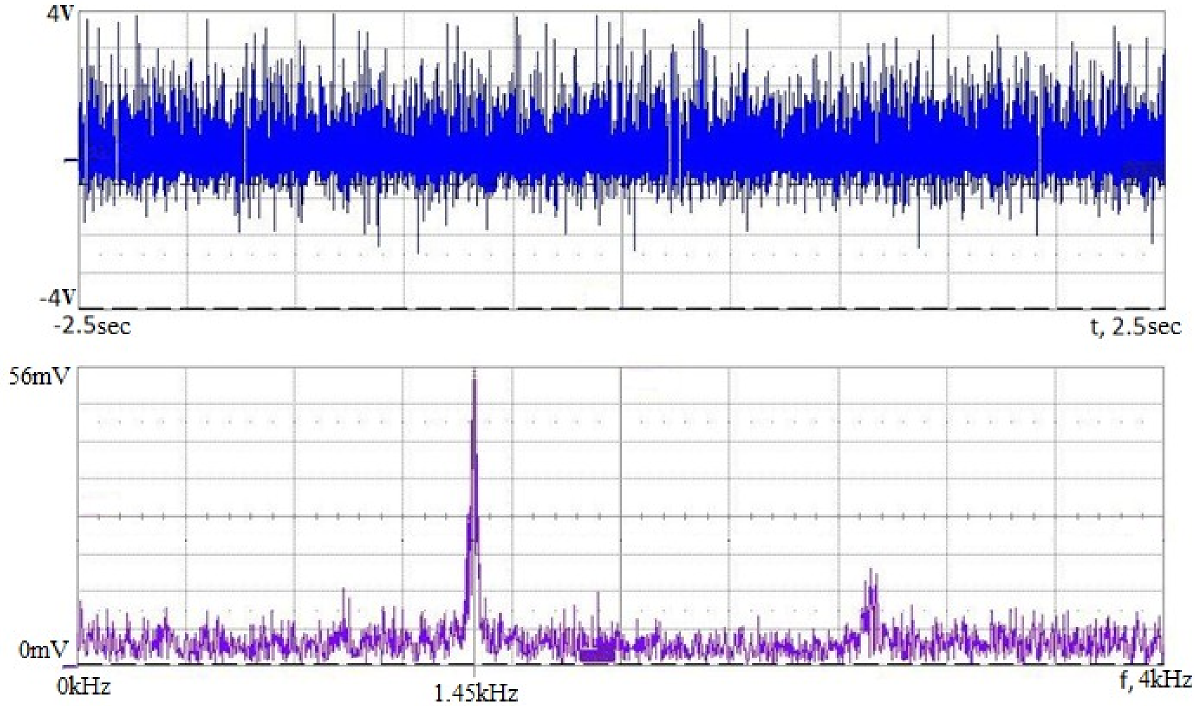


Fig. 2. **Pressure fluctuations changes vs time (a) and frequency (b) for the flow with the streamlined body - a cylinder with a notch:** P_{out}/P_0=0.43, G=215 l/min, 1B=1MPa, Amax=0.056MPa $A_ф$=0,001MPa.

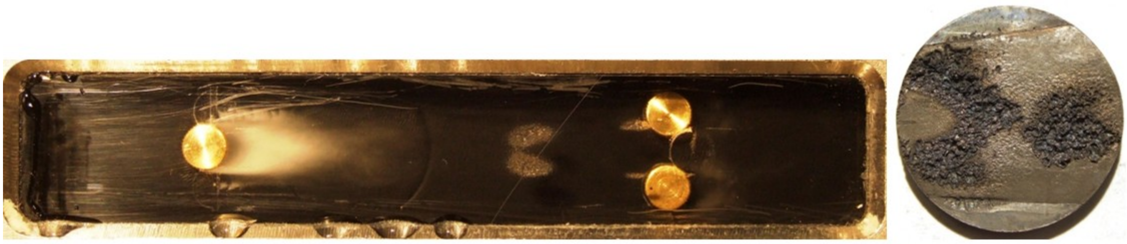


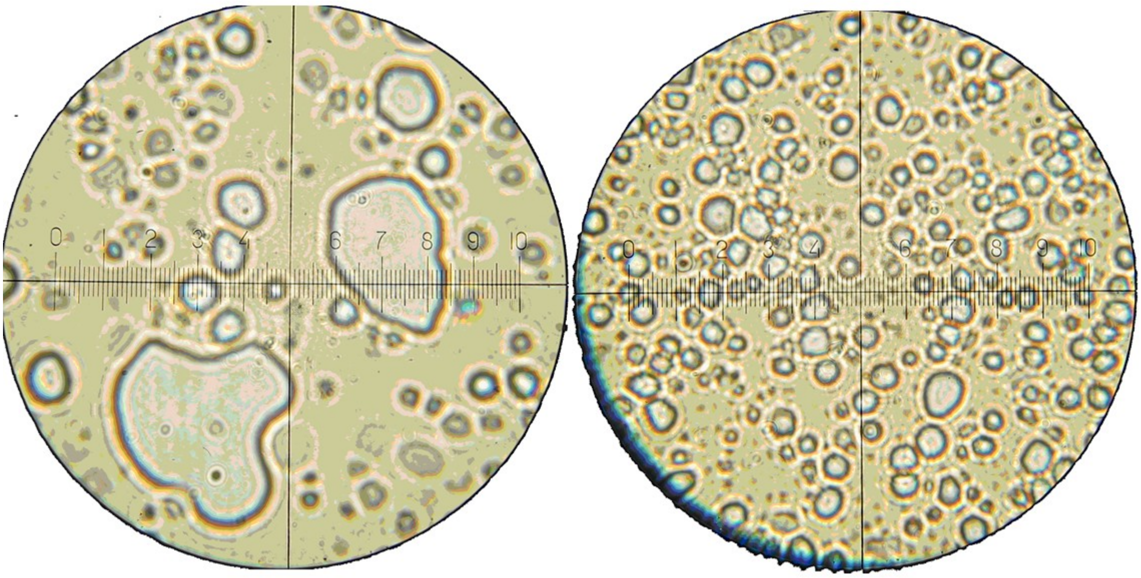
Fig. 3. **Pictures of the flow pattern in the generator channel and cavitation traces at the control sample for the streamlined body - a cylinder with a notch**: P_{out}/P_0=0.374, G=220 l/min.

For example, Fig. 3 shows a picture of the flow pattern behind the streamlined bodies and the erosion traces from the surface of the control sample in the flow generator channel for the mode, corresponding to the maximum carryover.

Fig.4. **General view of the unit for water-oil emulsion preparation for combustion in the boiler furnace.**

It is visible that under given thermal and physical properties of the fluid flow, behind the first row of streamlined bodies a long cavitation area is formed. By that, location of entrainment traces and places of a collapsing the gas bubbles of cavitation sheet, defined by a sharp decline in its glow, are consistent with each other.

Water-fuel emulsion is prepared on the basis of Udmurt deposits of crude oil and M-100 oil under natural conditions. A picture of installation for crude oil processing [6] is shown in Fig.4, and the structure of the initial crude oil and oil-water emulsion is presented in Fig.5.



a) b)

Fig. 5. **The structure of local energy resources (crude oil):** a) – initial; b) – prepared for combustion in a form of the water-fuel emulsion.

Table 1 shows the measurement data and the results of quantitative chemical analysis of oil and fuel oil samples. Numbers of samples correspond to the following fuel:

Sample 1 – initial fuel oil

Sample 2 – initial fuel oil + cavitation treatment

Sample 3 – initial fuel oil +7% of water + cavitation treatment

Sample 4 – initial fuel oil +10% of water + cavitation treatment

Sample 5 – initial oil

Sample 6 – initial oil + cavitation treatment.

There were carried out industrial tests of the technology for pre-combustion and combustion of oil emulsion in DKVR-10/12 steam boiler, as in the initial state, and prepared for combustion in a form of the water-fuel emulsion (Fig.5). Full-scale experiments showed that initial oil can't be combusted in the boiler furnace. Fuel burning occurs from the surface of large particles that do not burn completely; that results in their attacking the furnace tubes and falling on the furnace bottom. The following occurs: unacceptable chemical and mechanical fuel underburning, soot formation, contamination of heat transfer surfaces, sediments along the path (from the injectors to the chimney), reduction of boiler efficiency, explosive conditions. All this exclude the use of crude oil, being rather economically efficient in some cases as regional energy raw materials for local use in boiler-houses.

Table 1. **Results of chemical analysis of fuel samples.**

Analyte name	Component concentration						Measuring method, GOST*
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	
Mass fraction of water, Wp, %	10,2	9,5	16,4	18,0	0,9	0,5	2477-65
Mass fraction of sulfur, Sp, %	2,14	2,26	2,11	2,09	1,2	1,14	3877-88
Lower calorific value, $Q_н^р$, kcal/kg	8497	8590	8098	7727	9679	9686	21261-91
Lower calorific value calculated on dry substance, Q_l^d, kcal/kg	9530	9551	9798	9554	-	-	
Density, g/cm^3	0,982	0,985	0,979	0,980	0,913	0,912	3900-85

Note: State Standart (GOST)

The developed technology of preparation of oil emulsion for combustion [2,3,6] allowed to achieve excellent results under industrial operating conditions of equipment. Its application allowed to provide economically efficient fuel combustion (almost without chemical and mechanical underburning), to keep effective operation of the steam boiler, exclude flame impingement of the burning fuel on heating surface and practically approach to the conditions of natural gas combustion (Fig.6).

a) b)

Fig. 6. **General view of pulverised oil combustion in the furnace of DKVR-10/12 boiler:** a) burning flame of crude oil (view through the furnace observation door) – initial variant; b) burning flame of the same oil, prepared for combustion as the water-fuel emulsion.

As can be seen from the results of table 1, the main indicators of hydrocarbon fuels and water-fuel emulsions are close to each other. The major problem in their use is to provide an economically efficient and reliable combustion process.

As can be seen from Fig. 5, 6 crude oil combustion in DKVR-10/12 steam boiler essentially depends on its pre-combustion. Water-oil emulsion preparation under the proposed technology allows to use it in DKVR-10/12 boiler plant keeping high technical and economic efficiency, reliability and safe operation of equipment, that shows the prospects to proposed technology of liquid fuel preparation based on oil for combustion in boiler plants.

Conclusions

1. Crude oil combustion is unacceptable in steam boiler furnaces without their special modernization due to the following reasons: incomplete fuel combustion, pollution of heat transfer surfaces of the furnace path and appearance of flammable and highly explosive sediments of incomplete fuel combustion products, increased flue gas toxicity.
2. When preparing crude oil for combustion in a form of the water-fuel emulsion complete fuel burning is achieved (at almost zero chemical and mechanical fuel underburning), which eliminates the accumulation of unburned fuel in the fuel path of the boiler and its spontaneous ignition, leading to emergency situations. It does not require upgrading the furnace and burner units of the boiler.
3. Local using of crude oil as energy fuel (in the water-oil emulsion form) significantly reduces transportation costs, capital and operating costs for implementing the technological process of fuel combustion. It also reduces the harmful effect on natural ecosystems, provides high reliable operation of power equipment, which ultimately leads to high technical-economic and environmental indicators at heat and power generation.

REFERENCES

1. **Б.П. Туманян.** Научные и прикладные аспекты теории нефтяных дисперсных систем. М., Изд-во «Техника», 2000, 336 с.
2. **В.И. Кормилицын** Экологические аспекты сжигания топлива. // М.: Издательство МЭИ, 1998. – 336 с.
3. **Р.Ф. Ганиев, В.И. Кормилицын, Л.Е. Украинский.** Волновая технология приготовления альтернативных видов топлив и эффективность их сжи-

гания. – М.: НИЦ «Регулярная и хаотическая динамика», 2008, 116 с.

4. **Р.Ф. Ганиев, Л.Е. Украинский.** Нелинейная волновая механика и технология. – М.: НИЦ «Регулярная и хаотическая динамика», 2008, 703 с.
5. **В.В. Рождественский.** Кавитация. Л., Изд-во «Судостроение», 1977, 247 с.
6. **В.И. Кормилицын, Д.Н. Астахов.** Патент 2282492. Способ обработки материалов и устройство его осуществления. Опубликовано 21.08.2003.
7. **М.А. Промтов.** Кавитационная технология улучшения качества углеводородных топлив. Химическое и нефтегазовое машиностроение, 2008, № 2, с. 6-8.
8. **В.И. Кормилицын, М.Г. Лысков.** Огневое обезвреживание сбросных вод и энергетическая утилизации содержащихся в них нефтепродуктов и других органических веществ // Вестник МЭИ. 1995, №3, с. 47-49.
9. **О.В. Шмырков, Н.Б. Юшков.** Кормилицын В.И. Исследование характеристик плоского волнового генератора проточного типа с различными телами обтекания // М.: Инженерный журнал. Справочник. №2, 2013, с. 12-19
10. **П. Чжен.** Отрывные течения. Том второй. – М.: Издательство «Мир», 1973 – 280 с.