Part 4

COMPLEX TECHNOLOGIES OF RED UCTION OF ENVIRONMENTAL POLLUTION FROM THERMAL POWER PLANTS

4.1. Combustion of water-oil emulsion in steam boilers

4.1.2. Research and experience of water-oil emulsion application in TGMP-314 and TGM-96 boilers

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ABSTRACT

The issues relating to combustion of water-oil emulsions int large power boilers of CHPP-23 - a branch of JSC "Mosenergo", are considered. The aim was to determine the main indicators of their work and to identify new ways to control emissions of pollutants discharged with flue gases into the atmosphere.

In recent years more and more attention is paid to thermal engineering issues related to fuel economy and environmental protection. This is connected with constantly toughened environmental requirements for power facilities.

At the same time, the cost of energy carriers, especially liquid ones, is continuously increasing. Therefore, there is a need to use cheaper and hence low-quality types of fuel. In this regard, the use of water-oil emulsions is promising. The core of their development is the known data on intensification of the process of fuel combustion (water + oil) in the boiler furnace.

Application of the oil emulsification system makes a noticeable economic benefit, since its implementation results in more rational use of fuel combustion heat. The introduction of this technology at the operating TPPs does not require large capital investments and substantial changes in scheme of black oil facilities.

Burning of water-oil with considerable content of moisture leads to serious problems in maintaining stable regime parameters of boilers.

When burning oil, in addition to water and carbon dioxide, more than two hundred pollutants are emitted. Among them there are particles of soot, sulfur, nitrogen and carbon oxides, and hydrocarbons, the most dangerous of which are carcinogenic benz(a)pyrene.

The main part of harmful substances are synthesized in the middle and back sections of the flare of burning flame. At the same place, as a result of incomplete combustion, soot is formed, which is to be removed from the surfaces of heat exchangers.

Another problem, complicating the environmental situation, is continuous accumulation of ballast water and its utilization. Methods of purifying wastewaters from oil-products, applied now, are very expensive and not always highly efficient. This refers specially to the purification of highly polluted waters. Use of wastewater as additional water, enables to expose their considerable amount to fire neutralization (up to 20% of fuel per a boiler). This allows to switch the power plant to a low-waste technology.

For example, switching BKZ-75-39 boiler to water-oil emulsion combustion allowed to conduct fire neutralization of around 1 t/h of wastewaters, contaminated by oil products. By that, the boiler burning water-oil emulsion worked steadily. Switchboard instruments even fixed some increase in steam-production capacity at a constant flow rate of the original oil.

Fuel oil always contains the gross water that creates technological and environmental problems. When storing oil, some portion of water is collected in the water lenses and settles at the container bottom. Getting in the pipelines, and then to fuel injectors, these water inclusions cause uneven burning and even stop the boiler.

If such coarse water-fuel mixtures with different water content are subjected to hydromechanical high intensity treatment in the cavitation field, they are converted into an emulsion of "oil-water", in which water is in a finely dispersed phase.

The presence of a finely dispersed phase of water in the fuel emulsion has a positive effect on fuel oil combustion processes at the micro level (on a scale of one drop) for the following reasons.

Firstly, when the size of the dispersed water phase ranges from 6 to 20 microns, as a result of its rapid boiling-up, there happen micro explosions of droplets in the combustion space, which greatly increases the contact surface area of the fuel with air, and improves the combustion process.

Secondly, boiling of fine water particles with a diameter of 1 ... 5 mm, and gradual steam bubble growth (above 20 microns) on place of large inclusions, leads to increased volume of oil droplet, thereby reinforce the diffusion fluxes of light fractions to its surface and their evaporation.

At the macro level (at scale of a furnace), when burning water-oil emulsion, the water vapors are a physical exciter of convective homogenization of the air-fuel mixture, which leads to smoothing the uneven gas concentration and temperature fields in the furnace.

An important feature of the process of entering additional moisture in the combustion zone is the dissociation of water vapors at high temperature for H^+ and OH^- ions. OH^- ion, being a strong oxidant, reacts with the products of fuel underburning: CO, CH, multinucleated hydrocarbons (benz(a)pyrene - is also underburning). This leads to significant reduction in concentration of these substances in the flue gases. A good confirmation of this are the experimental results [6] in case of natural gas combustion with the introduction of extra moisture, when extra moisture (water) was simply injected into the combustion zone through special nozzles. In these experiments it was found that CO and benz(a)pyrene concentrations in flue gases reduced even more sharply than NO_x concentration. H^+ ion is more active then the atom of nitrogen (and even more then N_2 molecule). It reacts with free oxygen and thus helps to reduce the formation of nitrogen oxides. This mechanism of influence of the moisture in the combustion zone on formation of harmful substances also works in case of oil combustion.

The total effect of intensification of burning on the material balance of the process is reduction of critical excess air by 5 ... 10%. And this reduces the volume of the synthesized nitrogen oxides by 15 ... 45% as well as benz(a)pyrene emissions.

Due to the activating effect of finely dispersed water phase in the emulsion, time of fuel preparation and combustion decreases by 20 ... 25%; the flame length is shortened as well. By this reason, soot concentration in the combustion products declines by 90%. The best results in reducing benz(a)pyrene emissions are achieved at the size of the dispersed water droplets of 1 ... 10 microns [4].

The accompanying effect of reducing the formation of soot and coke is also a changing of the structure of their deposits on convective heating surfaces of the boiler. They either do not exist or become friable and easily removed.

Effect of finely dispersed water on suppressing the emissions of "thermal" oxides is expressed in the fact that the maximum temperature of the flame is reduced by 90-100°C. In addition, the critical air excess becomes lower due to intensification of heat-mass-exchange processes through steam-explosive crushing of drops.

It is known that in case fuel oil is being stored for a long time, there is a process of fuel aging, accompanied by formation of high viscous clots and separation of solid particles such as polycarbon and carboid. This reduces the chemical activity of fuel oil and its dispersibility, which leads to coking of nozzles, increase in emissions of soot in the atmosphere, saturated with benz(a)pyrene, and its intense deposition on convective surfaces.

For avoiding of these technological and environmental "troubles" it's helpful to prepare water-fuel emulsions in storage tanks, by means of hydrodynamic cavitation blending machines and treat the fuel in hydrodynamic activator, placed in front of the boiler nozzles. In hydrodynamic activator occurs destruction of fuel oil in the range of mechanical crushing to mechanical cracking of hydrocarbon compounds. It results to increase in the reaction surface of the solid phase, break of non-sprayable clots. Moreover, there arise molecular fragments, free radicals, which have a high reaction activity. And this significantly reduces coking of injectors, shortens the flame of combustion, reduces air emissions of soot, carbon monoxide and benz(a)pyrene, reduces drifts of heat transfer surfaces with soot.

Studies have shown, that activation of water-oil emulsions directly before the boiler not only increases the content of water inclusions of about 5 microns in the emulsion, which contribute to secondary atomizing, but as a result of high stress and shear rates in the "hard" cavitation field, also leads to destruction of the smallest colloidal clots, polycarbons and carboids, formed in the process of fuel oil aging during its storage. Exactly these components are a major cause of mechanical underburning of fuel (q_4) and air emissions of soot and CO. At the same time, free highly reactive radicals are formed. It happens due to mechanical cracking phenomena of branched molecular chains of petroleum products. The result of such mechanochemical transformations is seen in the increasing transparency of the flame, shortening of its length, reducing of nozzle coking and provides an opportunity to reduce the temperature of spray by 10...15°C.

Successful application of water-oil emulsions is explained, above all, by their quality. The quality of any emulsions is determined by dispersity that affects the emulsion stability, viscosity, electrical conductivity and other properties. The higher is dispersity, that is, the higher is the number and the smaller are the drops of water and the less different in magnitude from one another they are, the more even is water distribution in fuel, more stable is emulsion and higher is its quality.

Equipment, the operation principles of which are based on using the phenomenon of cavitation, allows us to obtain a high-quality emulsion. Such equipment includes: rotary-pulsation devices, hydro-dynamic acoustic generators ("whistles ") and ultrasonic emulsifiers. All of these devices allow to obtain high-quality emulsion (average diameter of the droplets are 1...3 microns). However, because of some drawbacks they have, the devices are not widely spread. Thus, the acoustic "whistles" differ for their difficulty of configuring and maintaining an effective processing mode during operation. Ultrasonic emulsifiers are expensive and complicated. They require special care. In addition, these devices have low productivity – up to 3 m^3/h. Rotary-pulsation apparatus are suitable only for the processing of pure liquids (working clearances are of 60...80 microns).

The above drawbacks don't have hydro-dynamic cavitation blending machines and activators, the hallmark of which is the relative simplicity of their construction, easy setup for an effective processing mode, easy operation, high reliability and high performance.

The phenomenon of cavitation arises in a moving fluid, as a rule, after local hydraulic resistances. For the cavitation it's necessary to have such a regime of fluid motion, at which pressure in a particular area will be below saturated steam pressure of the liquid at a given temperature. By that, in the liquid volume the formation and growth of cavitation bubbles is observed. Growth of bubbles is due to the pressure difference before and after the hydrodynamic cavitation blending machines:

$$\Delta P = (P_{sp} + P_g) - P_l$$

where P_{sp} - saturated steam pressure of the liquid at a given temperature; P_g - pressure of dissolved gases within a bubble; P_l - an external pressure in a liquid.

The greater is ΔP, the faster is the speed of cavitation bubble growth. When the cavitation bubble gets with the flow in the area of high external pressure, ΔP becomes negative, this leads to the collapse of the bubble. The collapse process is accompanied by energy release in a microscopic volume and as a consequence, formation of cumulative jets and micro-waterhammers. Thus, due to the collapse of a significant amount of cavitation bubbles, in a liquid the processes of highly intense mass transfer occur, that is used for the preparation of homogeneous and fine water-fuel emulsions.

In hydrodynamic cavitation blending machines the reduced pressure in a stream below the saturated vapor pressure is achieved by flow acceleration to up speeds 10...15 m/s.

Blending machine is flow compartment, on the axis of which one or more cavitating bodies are installed. When the cavitating body is flown around, the flow is accelerated in the place of constriction, wherein, in accordance with Bernoulli's equation, the pressure in the flow decreases, which leads to the formation and growth of cavitation bubbles. Cavitation bubbles form a sort of cloud behind the cavitating body, called cavity. Over the cavitating body the flow rate drops, the pressure increases, which leads to a collapse of cavitation bubbles and to intensive emulsification.

As indicated above (1), the cavitation bubble can exist at $\Delta P>0$. It' evident that when the flow rate increases, the value of P_l decreases, leading to more intensive growth of the cavitation bubble. In practice, it appears as a more advanced cavitation regime and increasing the size of the cavity, resulting to a more intense emulsification. At the same time, increasing the flow rate reduces the residence time of the bubble in the area of low pressure, i.e. shortens the bubble lifetime. As a result the higher is velocity of the fluid, smaller is the size of cavitation bubble at the beginning of collapse. However, with the velocity increase the hydrodynamic losses sharply rise. This may have negative effect on the performance of equipment, installed after hydrodynamic cavitation blending machines. Thus, the constructive calculation of hydrodynamic cavitation blending machines consists in obtaining the highest possible fluid velocity through the unit, ensuring hydrodynamic losses less than the limit value in these conditions.

It should be noted that in practice, there are no typical schemes of water-oil emulsion preparation, suitable for the efficient use at any power engineering object. This is explained by the fact that when designing the technological scheme one should take into account a variety of factors and parameters, characterizing a particular embedded object.

Therefore, for CHPP-23 conditions, there have been developed the two-stage technology of emulsification in hydro-dynamic cavitation mixers and the fuel activation before combustion in the hydrodynamic-cavitation activator for installation directly in front of the boilers.

The technology provides:

- oil recirculation with pumps of the first level through hydrodynamic cavitation blending machines to obtain a water-oil fuel emulsions with an average diameter of water drops of 20...30 microns; water-oil emulsions is being prepared throughout the entire volume of fuel oil tanks (Fig. 1);
- hydromechanical processing of water-oil emulsions in hydrodynamic activators, installed direct before the boiler at fuel oil pipeline of high pressure (Fig.2).

Activator characteristics are estimated so that the flow velocity in contact with the working section reaches the value, at which pressure falls below the saturated steam pressure at a given temperature. Cavitation field is formed after the cavitating profile, in which about 50% of the hydrodynamic turbulization energy refers to the acoustic component (in the field of ultrasonic oscillations). The result is destruction of the structures that have arisen in process of fuel storage and led to its destabilization. After hydrodynamic activator the average size of water droplets is 5…12 microns. Such dispersion is optimal in terms of reduced emissions of nitrogen oxides.

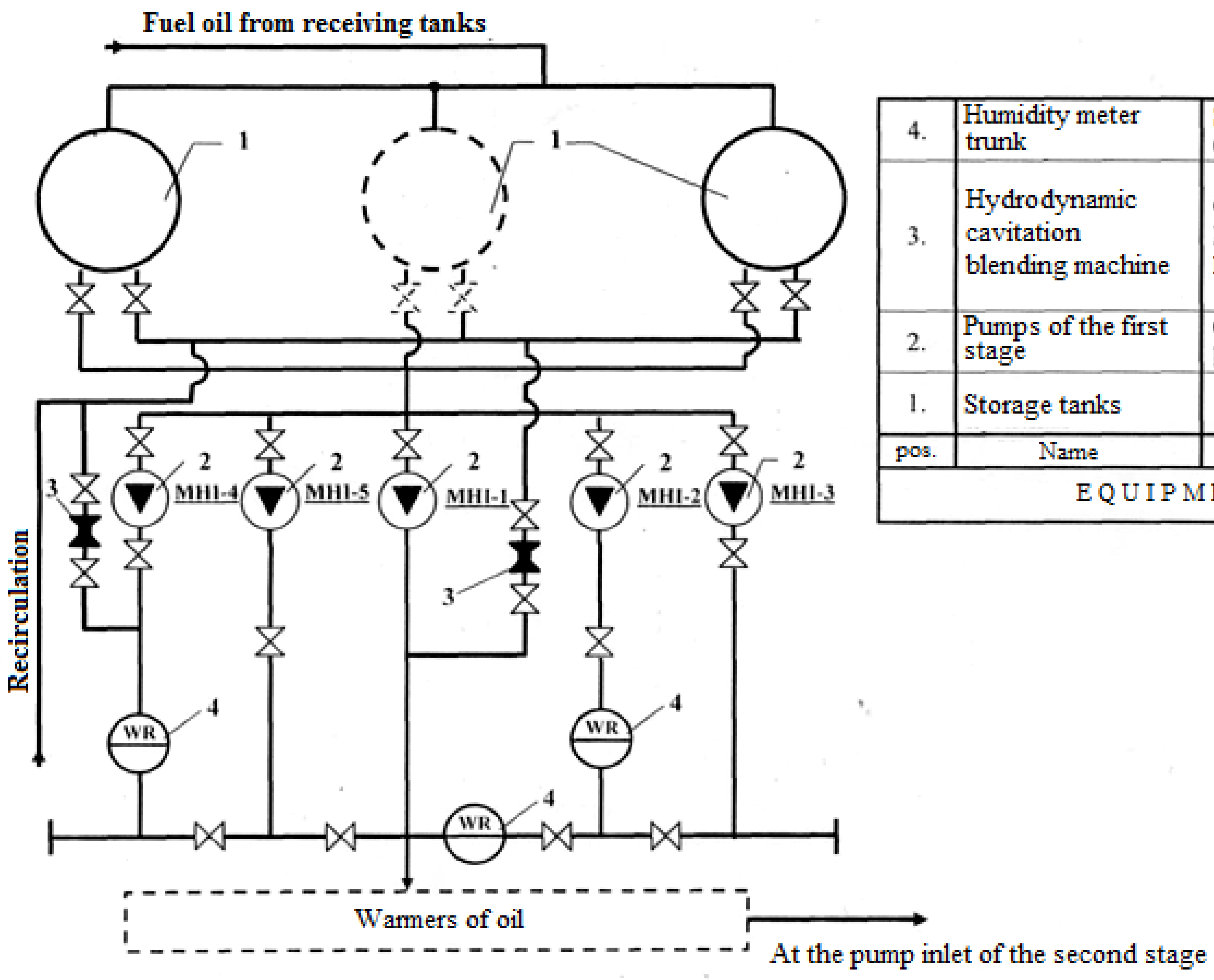
After introducing the two-stage emulsification and fuel activation before its combustion, for determination of moisture and dispersity there were taken the samples of non-emulsified oil, water-oil emulsions and activated fuel immediately before the injectors.

The sample of non-emulsified oil was selected from the vent piper of the first stage pump after prefilter.

The particulate composition of water-oil emulsion was determined using a microscope with a scale grid according to RD 34.44.215-96. Averaged results are shown in table 1.

Table 1. **Averaged results of particulate composition of water-oil emulsion**

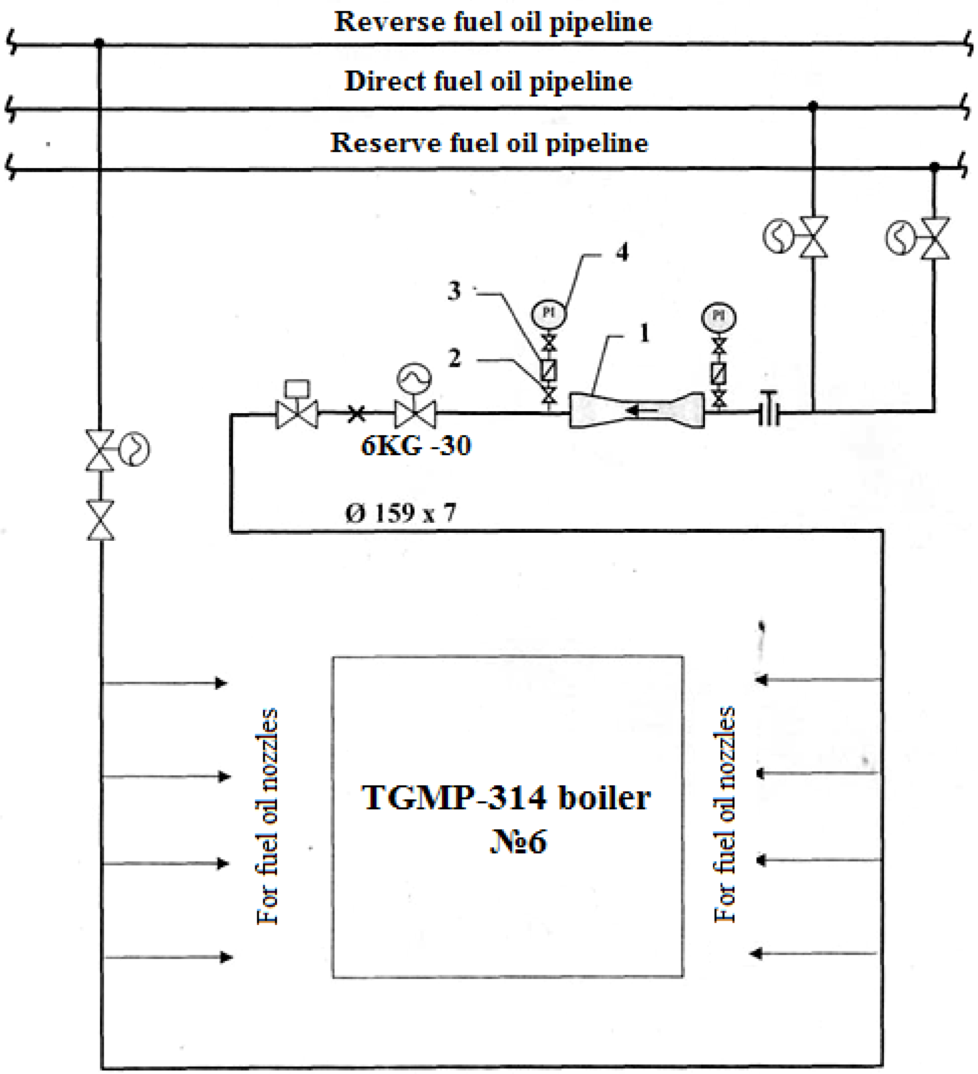
Samples	Water content, W^p, %	Dispersity of the aqueous phase	
		Size of water droplets, microns	Number of drops in the field of view, % of the total amount
Non-emulsified oil	9,6	5…15	38
		15…30	36
		30…50	24
		50…100	2
Water-oil emulsion	9,3	5…10	50
		10…15	33
		15…30	17
		over 30	–



EQUIPMENT LIST

pos.	Name	Characteristic	Amt.	Note
4.	Humidity meter trunk	Scale 0…20%	3	Inst. in 1998 y.
3.	Hydrodynamic cavitation blending machine	Q=420 m³/h, H=0,7 MPa, Du250	2	Inst. in 1993 y., replaced in 2000 y.
2.	Pumps of the first stage	Q = 450 m³/h, H = 0,5 MPa	5	
1.	Storage tanks		8	

Fig.1. Installation scheme of hydrodynamic cavitation blending machine after the pumps of second stage



№	Name	Designation	Characteristic	Amt.	Note
4	Pressure detector	MP4-U	Scale 0...10MPa	2	
3	Disengaging vessel	RS-25	P_y 250MPa	2	
2	Cutout valve	588	D_y10 Ru 250	4	
1	Hydrodynamic cavitation activator	GKA	Q_{max}=80 t/h P_p=3,8 MPa ΔP_{max}=0,35MPa	1	

EQUIPMENT SPECIFICATION

SYMBOLS:

- intercept (emergency) valve;
- gate valve with electric driver;
- orifice gage;
- repair plug.

NOTES:

1. This drawing is considered with the scheme oil steam traced pipeline of power TGMP-314 boiler №6 KTC CHPP-23 branch ISC "Mosenergo";
2. Conventionally shows part of the oil steam traced pipeline scheme

Fig.2. Installation diagram of hydrodynamic cavitation activator before the boiler

To activate fuel directly before the nozzles, hydrodynamic cavitation activators were installed on direct fuel oil pipelines of TGMP-314 boilers №5 and №7 in 2000, in 2002 — on boiler №6, in 2003 — on boiler №8.

Hydrodynamic cavitation activator is installed at TGMP-314 boiler before the head *valve* on a straight section of fuel oil pipeline ∅ 159x7. Calculation of hydrodynamic activator is fulfilled according to the following initial data:

- working pressure — 3,8 MPa;
- conditional pressure — 6,3 MPa;
- maximum fuel oil flow — 80 t/h;
- temperature of the medium, °C — 120…140;
- maximum permissible pressure loss at hydrodynamic cavitation activator — 0,35 MPa;
- weld joint of hydrodynamic cavitation activator under the pipe Ø 159x7.

In the working area of hydrodynamic cavitation activator, cavitating bodies in the form of a curvilinear profile of least resistance are installed (Fig. 3).

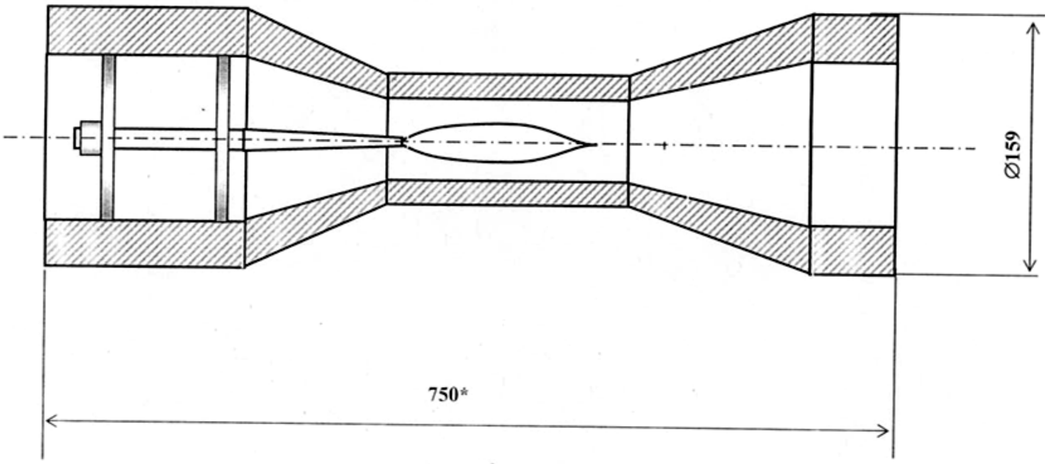


Fig. 3. Hydrodynamic cavitation activator (general view, cross section)

Mode of cavitation in the working area of hydrodynamic cavitation activator achieved due to pressure reached 0,2…0,35 MPa. Control characteristics of the flap provides pressure support required for normal operation of the injectors.

In the process of adjustment and testing of hydrodynamic cavitation activatore there were taken the samples of fuel oil to determine the moisture content, viscosity and content of mechanical impurities.

Table 2 shows the averaged data of water-oil emulsion analyses obtained from testing.

Table 2. **Results of water-oil emulsion analyses**

Place of sampling	Water content, W^p, %	Dispersity	Mechanical impurities, %
Straight fuel oil pipeline of block №6 (before hydrodynamic cavitation activator)	11,1	3…6 microns – 56 %; 6…12 microns – 28 % 12…20 microns – 16 %	0,17
Straight fuel oil pipeline of block №6 (after hydrodynamic cavitation activator)	10,9	3…6 microns – 79 %; 6…12 microns – 18 % 12…20 microns – 3 %	0,022

CONCLUSIONS

1. Despite of high initial moisture content of fuel oil the boiler performance has been maintained. Disperse composition of water after hydro cavitation treatment significantly decreased. The amount of mechanical impurities obviously remained the same, but they have greatly destructed into small drops. This increased combustion efficiency and reduced fouling of boiler heat transfer surfaces with soot.

2. In our opinion, the best way to prepare fuel oil for burning, regardless of the moisture content, is its two-stage treatment in the cavitation field.

REFERENCES

1. **В.М Иванов.** Топливные эмульсии. М.: Издательство Академии наук СССР, 1962
2. **Р. Кнэпп,** Дж. Дейли, Ф. Хэммит. Кавитация, под ред. В.И.Полежаева. " М.: «Мир», 1974.
3. **В.А. Корягин.** Сжигание водотопливных эмульсий и снижение вредных выбросов. С..Петербург «Недра», 1995.
4. **И.В. Галас,** О.В. Морозов, Ю.М. Усман. Влияние эмульгированного мазута на выбросы вредных веществ. Энергосбережения и водоподготовка. №3, 2000 г.
5. **О применении водомазутной эмульсии** для сжигания в котельных установках, Булгаков Б.Б., Булгаков А.Б., Преснов Г.В., Турченко В.И. и др. М.: Энергетическое строительство, 1995, №6.
6. **М.Г. Лысков,** В.И. Кормилицын, А.А. Румынский. Комплексная экосовместимая технология сжигания мазута в виде водо-мазутной эмульсии и природного газа с добавками сбросных вод. Теплоэнергетика, 1996, №9.

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