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Hydrodynamic treatment of water – black oil blends

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The results on developing and using a device for preparing liquid fuel blends based on black oil and water mixture are presented. Such blends can be used in steam boilers. Fuel components are mixed sequentially at four stages with the use of jet mixing, swirling, hydrodynamic cavitation, and dispersion. This device was tested for preparing water – black oil blends with different water content when it was incorporated into the fuel system located in the boiler room. Comparison of data on burning the prepared WBOB and commercial black oil M-100 showed that the use of WBOB with a different water content allowed specific fuel saving up to 11% for the tests considered. In addition, analysis of the furnace gases revealed that the total discharge of toxic substances was reduced on the average by 45%. Thus, the WBOB application enables to resolve two important problems: to save hard-to-get liquid fuel and to decrease the anthropogenic impacts on the environment.

Key words: water – black oil blends, stages of mixing, fuel saving, hydrodynamic treatment

1. INTRODUCTION

A rapid depletion of natural resources of conventional hydrocarbon fuels and their ever-increasing costs have given an impetus to design new technologies and equipment for making alternative fuels. Of late, such technologies are under development and allow the amounts of conventional hydrocarbon fuels to be decreased at reduced environmental impacts. One of the evolving directions to overcome this gap is to develop facilities for hydrodynamic treatment of liquid hydrocarbon fuels and to prepare fuel blends suitable for use in steam boilers and internal combustion engines (ICEs). To do this, fuel is supplemented with additives that enhance the combustion process and reduce environmental impacts [1].

Fuel blends based on conventional hydrocarbon fuels and additives prepared by alcohol fermentation or extraction from vegetable raw material are highly promising. At present, the use of these fuels becomes economically justified, makes a base for replacing conventional hydrocarbon fuels, expands the raw material resources for fuel preparation, and also facilitates the transportation of such fuels to the place of their use [1, 2]. The preparation and use of liquid fuel blends with required physical and chemical properties permit operation processes in ICEs to be improved purposefully, and this will refine their operating parameters [1, 2].

Fuel blends applied in steam boilers and industrial furnaces are based on black oil. In this case, efficient use of black oil can be achieved in the following manner [3]:

1. When the burning completeness of black oil is provided, its consumption decreases, and the cause for soot formation is eliminated. This will save fuel, and the contamination of atmospheric air will be avoided.

2. When an optimum viscosity of black oil is kept and the combustion process is controlled systematically, the air excess in combustion products decreases.

3. When the waste gas temperature is decreased, since the furnace gas temperature is increased by 20 °C, the efficiency of a steam boiler reduces by 1–1.5% with increasing heat loss due to waste gases.

The choice of optimal methods of using black oil is specified by its composition and properties and also by its application. One of these methods is the application of water – black oil blend (WBOB).

It is known [3, 4] that black oil used in steam boilers and industrial furnaces usually contains water, and this fact has a pronounced influence on the blend combustion heat. Each per cent unit of the blend moisture content reduces the blend combustion heat by 100 kcal, of them 94 kcal are not produced by decreasing the amount of the combustible fuel component, and 6 kcal are spent for evaporating additional 1% of water [3]. Black oil is saturated with water during transport and storage. Moreover, when high-viscous black oil is poured out from storage tanks, it is usually pre-heated by live water steam. This additionally increases the fuel moisture content. However, according to practical standards, the moisture content of furnace black oil should not exceed 5%.

As the density difference of water and black oil is low, water can be distributed nonuniformly in a fuel mixture in the form of layers and coarse drops. This hampers black oil burning since the fuel supply to the boiler is sometimes cut off. So, when black oil with a high water content is dewatered, or it is passed through emulsifiers to get a fine-disperse fuel mixture – WBOB – this raises essentially service expenses for steam boilers and industrial furnaces [3–5]. The latter approach is one of the most effective methods of improving the burning quality of liquid fuel and reducing environmental discharges.

This work presents the results of designing the devices for preparing WBOBs when a liquid fuel blend undergoes hydrodynamic treatment. Under such non-chemical treatment of liquid fuel blends, which has been based upon the data and actual experience of usage of homogenized fuel blends in fuel systems of power plants, the technical and economic effect has been found to depend not only on the dispersion degree and the content of additives in the blend, but also on the effect of the hydrodynamic factors on the physical-chemical structure of fuel and the methods of application of fuel blends [1].

2. COMBUSTION PECULIARITIES OF WATER − BLACK OIL BLEND

A water – black oil blend is a complex liquid fuel composed of two liquids with a different boiling point, in which small water drops are distributed rather uniformly over fuel volume. The burning enhancement of water-saturated liquid fuel, when the latter is converted into WBOB, can be explained by microexplosions of blend drops at combustion [4–6]. The water inside a blend drop, when heated, is transformed into vapor and forms vapor bubbles. When the pressure forces of water steams, which tend to expand, exceed the already attenuated surface tension forces of the fuel film, the drop surface undergoes destruction, i. e. a microexplosion takes place. Such a distinctive feature of WBOB combustion appears because of a difference between the boiling point of water (100 °C at normal pressure) and that of black oil (up to 300 °C).

When emulsified fuel particles explode directly in the furnace, air is additionally blended with fuel vapors. By improving the stirring of fuel particles and air due to microexplosions, one can decrease the air excess to a critical level and thus increase the boiler efficiency [3]. This not only speeds up the combustion process, but also allows fuel to be burnt with a less maximum flame temperature. Because of this, nitrogen oxide formation in combustion products is suppressed under the same completeness of fuel burning. Water steams in the combustion zone accelerate the burning-out and thus decrease the amounts of formed soot and cancerogen discharges. The soot amounts at all air excesses are smaller than those at burning only pure black oil (decrease by 85–95%) [6].

Thus, WBOB application enables to resolve two important problems: to save hard-to-get liquid fuel and to decrease the anthropogenic impacts on the environment.

3. PREPARATION AND TESTING WATER − BLACK OIL BLENDS

The procedure of making liquid fuel blends proposed in this work is based on enhancing the mixing process when a fuel blend is dispersed and affected sequentially by several hydrodynamic factors (flow swirling, cavitation, dispersion) with regard to the dynamic parameters and geometric sizes of mixers used to prepare liquid fuel blends. Various types of dispersive devices have found wide use in making blends. Among these, best fit for use are devices resting on the principles of turbulence initiation and hydrodynamic cavitation [6, 7].

In turbulent motion, cavitation can generate and enhance emulsification. This phenomenon has given an impetus to design cavitation-vortex dispensers with moderate specific energy consumptions, with operating regimes of speeding-up emulsification, and with a high quality of the prepared blend.

To stabilize blends to be made, various emulsifiers are added. It is known [3, 4] that the stability of WBOBs is higher than that of other fuel blends. Firstly, this stability is attributed to the fact that black oil is a complex fuel containing aromatic carbons, paraffin, naphtha, asphaltenes, and resins [3]. Secondly, a comparatively high stability of WBOB also follows from the fact that the density of black oil (~950 kg/m^3) practically approaches that of water. Thirdly, the high viscosity of black oil hampers WBOB lamination at room temperature.

In this work, a distinguishing feature of WBOB preparation is the sequential four-stage treatment of fuel components to be mixed due to injection, swirling, hydrodynamic cavitation, and dispersion. Such fuel treatment has been implemented on the laboratory device for preparing fuel blends (the fuel blend output is 5 m^3/hr) (Fig. 1). This device has been designed by us at the A. V. Luikov Heat and Mass Transfer Institute of NAS of

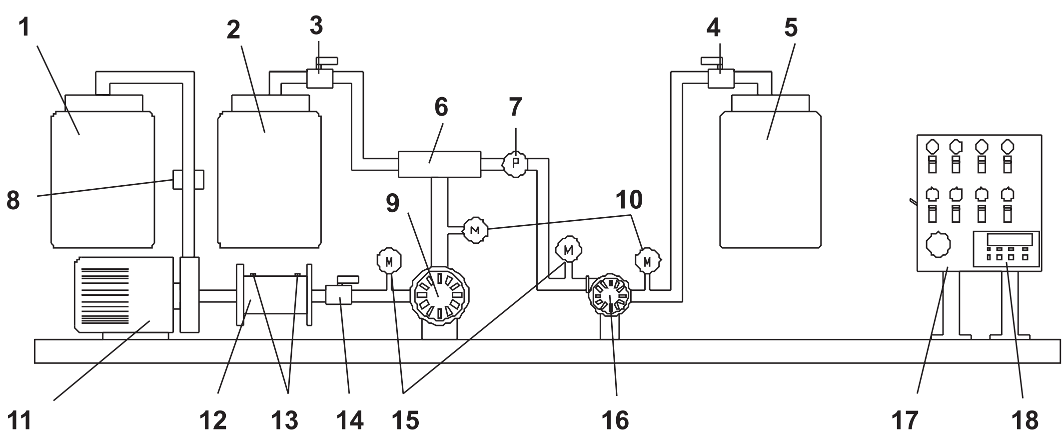

Fig. 1. Laboratory device for preparing fuel blends: *1, 2, 5* – tanks for blend components; *3, 4, 14* – valves; *6* – pre-mixer; *7, 10, 15* – manometers; *8* – acoustic flow meter sensors; *9, 16* – pumps; *11* – pump dispenser; *12* – jet ejector; *13* – acoustic pressure sensors; *17* – control panel; *18* – acoustic flow meter

Belarus in an effort to prepare stable high-disperse liquid fuel blends.

The device is equipped with three facilities – pre-mixer *6*, jet ejector *12,* where cavitation phenomena are being realized, and rotor-stator dispenser *11* (Fig. 1). The main component (fuel) of a mixture from tank *2* is intaken by swirling-type pump *9* into pre-mixer *6*, where it is pre-mixed with the second component supplied from tank *5* by pump *16*. The pre-mixer is designed on the principle of turbulent jet mixing of substances when the jet of the main component of the mixture is injected radially into the co-flow of the second component. Having passed through pump *9*, the mixture enters jet ejector *12*. The mixture is supplied through a confuser into the tube region of the jet ejector where cavitation flow conditions are set up; further, it is finally treated in disperser *11* and then poured out into tank *1*. So, over each working section of the device, the mixture undergoes a strong hydrodynamic treatment. Pressure at the pump outlet is measured by manometers *15* and at the pump inlet by vacuum manometers *10*. Pressure in the tube region of the jet ejector is measured by acoustic sensors *13*, and its indications are input into the oscillograph. The flowrate of an additional mixture component is measured by volume flow meter *7* and that of the whole mixture by acoustic flow meter *18* (relative measurement error ± 0.95%). The fuel-to-additive flowrate ratios are varied by valves *3* and *4* and the flowrate of the entire mixture by valve *14* installed behind pump *9*. The pumps are controlled from panel *17*. To analyse the indications of acoustic pressure sensors *13* and to make the protocol of the experiments, the working polace of the experimentalist was equipped with a TDS3012B oscillograph and a personal computer.

The approaches used in designing the laboratory device (Fig. 1) were adopted to construct the pilot installation shown in Fig. 2 and engineered for the preparation of WBOB with the water content of up to 20%.

The estimation of fuel saving in WBOB burning is associated with determining a number of parameters related to particular steam boilers and to blends [3]. The first group includes the parameters responsible for fuel quality, burning quality, possible and accurate measurement of black oil flowrate, furnace gas composition and temperature, furnace gas tightness, air excess, accurate blasting control, etc. The second group of parameters describes the quality of a blend to be burnt, i. e. water content and its dispersion degree in the blend. Usually, in industrial steam boilers the latter, two parameters are not controlled, although their optimal values are known from the viewpoint of both environmental requirements and keeping the burning process. It has been found [4, 5] that the optimal water content in the blend is close to 10% when water drop diameters are of the order of 10 µm.

In this work, the efficiency of using WBOB was checked from a comparative analysis of the data on burning WBOB and commercial black oil M-100 to support the fact that the saving of pure fuel (black oil) depends directly on the percentage of fine-disperse water drops in WBOB. To this end, the pilot installation (Fig. 2) was incorporated into the fuel system located in the boiler room at Parventus Silturns, Ltd. to cover partial heat consumptions of the Ventspils town (Latvia). Thermal energy in the boiler room was generated in four industrial steam boilers GM5014-250.

Fig. 2. Pilot installation for preparing WBOB

In order to detect and perceive the effects as mentioned above, to save conventional fuel, a number of parameters were controlled, among them the instantaneous flowrate of black oil, water content of black oil to be burnt, the composition and temperature of furnace gases, the flowrate and temperature of blast air, air excess in the fuel burner and the amounts of discharged black oil-added water per black oil ton.

Two tests were conducted in the pilot installation which was operating in two shifts (16 hours a day). First, the WBOB (15% of water content by volume) based on commercial black oil M-100 (6.2% of water content by volume) and technical water (black oil-added water) was made. Further, in the first test, the WBOB (500 tons) entered a tank filled with black oil M-100 (1000 tons). So, the ratio of the WBOB and black oil M-100 was 1 : 2. On recirculation in the pilot installation, the water content of the blend was 13.2%. In the second test, WBOB (500 tons) was mixed with black oil M-100 (500 tons) i. e. at the ratio 1 : 1. In this case, on recirculation, the water content of the blend was 15.4%.

Tables 1 and 2 contain experimental data on burning the prepared WBOB and commercial black oil M-100 (6.2% of water content by volume). The use of a WBOB with a water content of 13.2% enabled us to achieve the specific fuel saving of ~6% (Table 1), whereas for WBOB with a water content of 15.4% this index amounted to ~11% (Table 2). In addition, analysis of the furnace gases revealed that the total discharge of toxic substances was reduced on the average by 45% (of nitrogen oxides by 20–25%, of carbon oxide by 85%, of soot particles by 85–90%). This allows expenses for ecological fines to be reduced essentially.

Based on the obtained results, it is possible to calculate the annual money economy due to saving black oil. For example, at the specific fuel saving of ~6% it will be 33.42 tons · 365 days · 200 $ · 0.06 = 146 380 $ for the annual black oil consumption

Table 1. **Results of burning commercial black oil M-100 with water content of 6.2% and a mixture of black oil M-100 and WBOB (ratio 1 : 2) with water content of 13.2%**

Commercial black oil flowrate during 16 h of operation, ton	Flowrate of a mixture of black oil M-100 and WBOB during 16 h of operation, ton	Amounts of the vapor produced during 16 h of operation on black oil, ton	Amounts of the vapor produced during 16 h of operation on a mixture of black oil M-100 and WBOB, ton
35.62	35.35	464.2	452
Flowrate of pure fuel (black oil), ton	**Flowrate of pure fuel (black oil), ton**	**Specific flowrate of pure fuel needed to produce 1 ton of vapor, kg fuel / ton vapor**	**Specific flowrate of pure fuel needed to produce 1 ton of vapor, kg fuel / ton vapor**
33.42	30.69	71.99	67.89

Table 2. **Results of burning commercial black oil M-100 with water content of 6.2% and the mixture of black oil M-100 and WBOB (ratio 1 : 1) with water content of 15.4%**

Commercial black oil flowrate during 16 h of operation, ton	Flowrate of a mixture of black oil M-100 and the WBOB during 16 h of operation, ton	Amounts of the vapor produced during 16 h of operation on black oil, ton	Amounts of the vapor produced during 16 h of operation on a mixture of black oil M-100 and WBOB, ton
29.93	31.95	349.8	378.6
Flowrate of pure fuel (black oil), ton	**Flowrate of pure fuel (black oil), ton**	**Specific flowrate of pure fuel needed to produce 1 ton of vapor, kg fuel / ton vapor**	**Specific flowrate of pure fuel needed to produce 1 ton of vapor, kg fuel / ton vapor**
28.075	27.05	80.26	71.44

of 33.42 ton · 365 days = 12 200 tons and the black oil cost of 200 $/ton when 6% of fuel is saved. This corresponds to a half-year payback period of an emulsifying system.

4. CONCLUSIONS

Tests of the devices designed for preparing WBOB have revealed that it makes sense to use the proposed procedure of non-chemical hydrodynamic treatment of a fuel blend for reducing the pure fuel flowrate and the amounts of toxic substances to be formed when the blend is being burnt in steam boilers.

Analysis of the available information and the application of emulsified WBOBs allow to increase the burning efficiency of fuel and to gain in boiler efficiency. When water is nonuniformly distributed in the form of coarse drops, layers, etc., its presence in black oil to be burnt necessarily decreases the steam boiler efficiency because of the combustion nonuniformity in addition to consumptions for water evaporation. Thus, an efficient use of water-saturated black oil, or WBOB, is possible only provided that water is uniformly fine-dispersed over the entire volume. The use of WBOB makes it possible to decrease the amounts of toxic substances in exhaust gases. This gives the possibility to decrease fine sanctions due to reduced volumes of environmental discharges. Thus, as follows from the aforesaid, in steam boiler furnaces, the burning of WBOB prepared using black oil-added water is a promising method of decreasing the pollution of the urban-industrial environment and increasing the utilization of black oil-added waters, waste oils, etc. in the composition of WBOB.

This work is now in progress and will involve a research of liquid fuel blends of different composition and application.

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Nomenclature

ICE – internal combustion engine;
WBOB – water – black oil blend.

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VANDENS–MAZUTO MIŠINIŲ GAMYBA HIDRODINAMINIO APDOROJIMO METODU

Santrauka
Straipsnyje pateikiami įrangos skystajam kurui iš mazuto ir vandens paruošti sukūrimo ir panaudojimo rezultatai. Tokie mišiniai gali būti naudojami kaip kuras garo katiluose. Kuro komponentai yra nuosekliai maišomi keturiose stadijose, naudojant srovinį maišymą, sūkurius,

hidrodinaminę kavitaciją ir dispersiją. Šis įrenginys buvo naudojamas ruošti vandens–mazuto mišinius su skirtingu vandens kiekiu, kurie buvo tiekiami į katilinėje esančią kuro sistemą. Rezultatų palyginimas deginant paruoštus vandens–mazuto mišinius ir katilų mazutą M-100 parodė, kad vandens–mazuto mišinių su skirtingu vandens kiekiu naudojimas leido sutaupyti iki 11 % kuro. Be to, kūryklos dujų analizė parodė, kad bendras toksiškųjų medžiagų kiekis sumažėjo apytikriai 45 %. Taigi vandens–mazuto mišinių panaudojimas leidžia išspręsti dvi pagrindines problemas: sutaupyti sunkiai gaunamą skystąjį kurą ir sumažinti antropogeninės taršos poveikį aplinkai.

Raktažodžiai: vandens–mazuto mišiniai, maišymo gamybos stadijos, kuro ekonomija, hidrodinaminis apdorojimas

Игорь Кухарчук, Андрей Чорный, Вадим Гиль, Олег Пенязьков

ПОЛУЧЕНИЕ ВОДОМАЗУТНЫХ СМЕСЕЙ ГИДРОДИНАМИЧЕСКОЙ ОБРАБОТКОЙ

Р е з ю м е

Представлены результаты по разработке и применению устройства, предназначенного для получения жидкого топлива на основе смеси мазута и воды. Такие смеси можно использовать в паровых котлах. Компоненты топливной смеси смешиваются последовательно в четыре стадии с использованием струйного смешивания, вихревой обработки, гидродинамической кавитации и дисперсии. Это устройство применялось для получения водомазутных смесей с различным содержанием воды в топливной системе котельных. Сравнение результатов эксперимента по горению приготовленной водомазутной смеси и топочного мазута М-100 показало, что использование такой смеси с различным содержанием воды дает удельную экономию топлива до 11 % для рассмотренных случаев. Кроме того, при анализе топочных газов выявлено, что общее количество вредных выбросов в среднем снизилось на 45 %. Таким образом, использование водомазутных смесей позволяет решить две важные задачи: экономить дорогостоящее жидкое топливо и уменьшить антропогенное влияние на окружающую среду.

Ключевые слова: водомазутные смеси, стадии смешивания, экономия топлива, гидродинамическая обработка