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USE OF OIL-WATER EMULSION IN SWIRL BURNERS

Efficient combustion of unconventional fuels has come to the forefront of research in recent years by scientists in many countries due to the accelerating depletion of fossil fuels. With the development of computer technology, more and more attention is being paid to modelling using a wide range of specialised software at the expense of more accurate experimental studies due to expensive laboratory equipment and consumables. In this paper a brief review of experimental studies related to preparation and combustion of water-oil emulsion (WOE) with explanation of the process of micro explosion of fuel droplets and dependence of combustion efficiency on the percentage of water in the fuel is presented. An experiment on combustion of WOE using a patented innovative burner for a wide range of liquid and gaseous fuels was conducted. Based on a previously published article describing a wave disperser made by the authors, a mixture of fuel oil with water concentrations of 5 %, 10 %, 15 % and 20 % in WOE and once pure fuel oil was prepared and burned. The results of the analysis of the harmful emissions data show a decrease as the moisture content of the fuel increases. The most optimal moisture content as measured by the heat release rate of the water-oil emulsion is at 20 %.

Keywords: water-oil emulsion, dispersant, microburst, vortex combustion chamber, harmful emissions.

Introduction

The reduction of environmental pollution, especially NOx, is one of the most important areas of global research in the development of new combustion devices for conventional and alternative fuels. The global depletion of fossil fuels, and the tightening of environmental regulations, has led to a deepening of the understanding and improvement of approaches to combustion system design, taking into account the possibility of combustion of alternative fuels. One of such fuels is water-oil emulsion (WOE), providing ecological combustion with low level of harmful emissions. Combustion process of WOE is not fully studied and is based mainly on experimental data of laboratory studies.

Problems of energy resources saving and improvement of ecological condition of a heat and power facility depend in many respects on organization of qualitative fuel combustion (in a particular case, oil). However, taking into account the fact that all available technologies of fuel preparation and combustion itself are brought practically to perfection, and efficiency and ecological purity of boiler units in many cases leave much to be desired, the problem of searching constructively new methods in this area is acute. In this case, the application of a fundamentally new type of fuel – WOE is relevant in solving the set problems. Water-oil emulsion is a fundamentally new type of fuel, consisting of two liquids insoluble in each other: a globule of water and the surrounding film of fuel oil. According to experimental observations of many authors, when such drop hits the high-temperature zone of the furnace, water in the composition of WOE drops boils, turns into steam and, expanding explosively, breaks the surrounding film of fuel oil – the so-called «micro explosion» occurs. As a result of this process, the fuel oil droplet is crushed into many small droplets of «pure» fuel oil, flying in different directions [1].

Use of special dispersants is a more advanced approach to the process of obtaining WOE, implementing a continuous mode of their preparation and combustion in boilers and furnaces. The advantages of systems with a continuous mode of preparation and combustion of WOE are obvious. Most of the modern WOE preparation schemes use dispersing devices and are flow systems, in which WOE after preparation is fed for combustion [2]. Steam generation leads to expansion and deformation of the surrounding oil droplet and ultimately to its fragmentation. Microbursting is defined as a process during which a complete rupture of the oil droplet occurs, whereas if only part of the fuel oil droplet ruptures, the process looks like a bloat [3].

Despite the potential benefit of emulsified fuels, the detailed physical mechanisms that occur during microbursting and inflation are not clear. In an experiment [4], the homogeneous explosive boiling of a steam bubble inside a superheated water droplet was studied and the size of the steam bubble during its growth was measured. In a similar experiment [5], it was observed that during the explosive boiling the liquid particles bounced away from the liquid-gas interface, along with the bubble oscillations. So far, most of the experiments with emulsion droplets have focused on the combustion characteristics after secondary atomization induced by puffing/microburst [6]; thus, the overall dynamics of a single droplet cannot be revealed. The single droplet experiments investigated relatively large droplets (Ø (1 mm)) compared to those used in engines. In [7] it was found that the volume fraction of water and the amount of surfactants (surfactants) can influence the tendency to microburst. The size distribution of dispersed water subdroplets also has a significant effect on microbursting [8]. Experiments have recently been carried out in [9,10] with single droplets whose sizes were similar to droplet sizes in diesel engines (Ø (10 μm)). In the experiment [10] the effect of water content on microburst characteristics was investigated using a high-speed video camera. Rationale for the necessity of burning fuel oil as WOE is presented in detail in the author's works [11, 12]. In this regard, in [13] a fundamentally new device for preparation of watered-down fuel oil for combustion is proposed for implementation in boiler-houses. The device contains a housing made of several cylindrical rectilinear sections connected by bends, connectors for water and fuel oil supply, cavitation bodies located inside the cylindrical housing. It differs from its analogues in that the cavitation bodies are made of plates with a curved surface in the form of a straight helicoid. In comparison with the known devices for the preparation of WOE the proposed unit allows to prepare liquid fuel better due to the original design of cavitation bodies.

Comparative characteristics of black oil and WOE in relation to boiler units are presented in table 1 according to [14].

Table 1 – Main thermo-technical characteristics of WOE

Type fuel	Humidity, %	Heat of combustion, MJ/kg	Density, kg/m^3	Curing temperature, °C	Flashing point, °C	Parameters in front of nozzle	
						Temperature, °C	Viscosity, degree WU
Fuel oil M100	2	40,43	945	25	150	100	4
WOE-5	5	38,42	948	25	160	103	4
WOE-10	10	36,29	950	25	175	90	6
WOE-15	15	34,13	952	25	190	95	6
WOE-20	20	33,85	954	25	205	98	6

As shown in [15] the combustion process of WOE is accompanied by droplet fragmentation due to the emission of water vapour from the droplet. In addition to microparticulation there is a sharp increase in velocities of the fragmented droplets relative to the air stream. The emulsion droplet burns faster than an oil droplet of the same size which is evident from the experimental data (Table 2) [15].

Table 2 – Comparative data on combustion of drops of fuel oil and WOE

Fuel	Drop diameter, mm	Total combustion time of the droplet, s	Soot burning time, s
Fuel oil	1,1	3,30	1,4
WOE	1,1	2,48	1,1

A significant amount of experimental work is directly related to the combustion of WOE, the research was mainly carried out using single droplet weighting and free-fall droplet weighting methods [16,17].

According to experimental studies [18] compared to temperature, water has a greater influence on the viscosity of fuel oil. Low water content of 5% has a negative impact on combustion, meanwhile too high water content of 30% too increases the fuel density and viscosity, which in turn affects fuel atomisation characteristics and makes the combustion process unstable.

Materials and methods

M100 fuel oil was taken as the starting fuel for the experiment. The combustion stage is preceded by homogenisation of the water-fuel mixture using a dispersant. In the preparation of water-fuel emulsions, the qualitative choice of devices for the preparation of WFE is of great importance. The process was carried out using wave treatment dispersant [19]. The experiment was conducted in four cases with combustion of WOE with 5 %, 10 %, 15 %, 20 % concentrations of water and once with pure fuel oil. NO, NO_2, and SO_2 content in flue gases was measured with a DAG-500 gas analyser in order to analyse the effect of different water concentrations on emission rates of harmful substances. Thermoelectric transducer of TVR type (tungsten – rhenium) with measuring range up to 2200 °C was used to determine the temperature in the swirl burner device.

Results and discussion

The results on combustion of WOE 5 %, 10%, 15 %, 20 % concentrations of water and pure fuel oil showed patterns of changes in flame quality, its stability and significant differences in the amount of harmful emissions. Plots of dependences of harmful emissions and temperature on the quantitative content of water in fuel oil are shown in Figures 1–3. Values for NO and NO_2 are given in NOx.

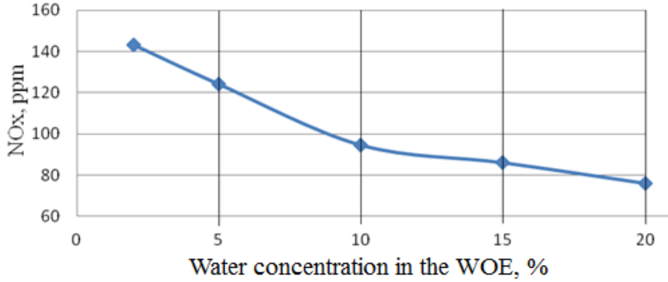

Figure 1 – NOx content as a function of water concentration in WOE

With increasing water concentration in WOE there is a significant reduction of nitrogen oxides in the flue gas composition from 145 ppm to 77 ppm. Under these conditions NO_2 increased to $\frac{NO_2}{NO} = 0{,}31$, compared to $\frac{NO_2}{NO} = 0{,}15$ pure oil combustion.

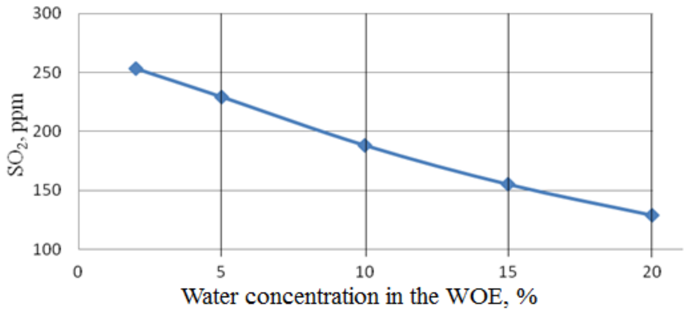

Figure 2 – SO_2 content as a function of water concentration in the WOE

Figure 2 clearly shows the reduction of sulphur oxide SO_2 content in the combustion products. Taking into account the sulphur content S_p = 2,4 %, the sulphur dioxide content in fuel oil combustion was 252 ppm, and when burning WOE with 20 % H_2O the figure was 129 ppm.

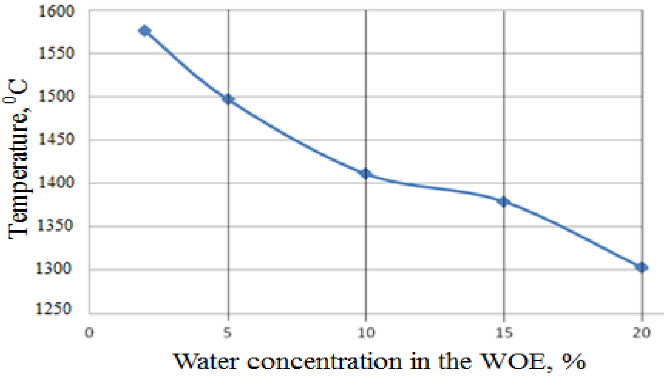

Figure 3 – Combustion chamber temperature as a function of water concentration in the WOE

Reduction of the maximum temperature limit in the combustion chamber of the innovative burner is observed when the H_2O content in WOE is increased in stages as shown in Figure 3.

As a result of formation of so-called «microbursts» during WOE combustion, as well as uniform distribution throughout the flame volume due to uniform distribution of oxidant and fuel, a decrease in temperature level is observed together with a decrease in emission of harmful substances in flue gases.

By creating an effective vortex in the innovative combustion chamber, the dwell time of fuel and oxidant in the combustion zone is increased. As a result of transition of a part of anhydride into sulphuric acid aerosols H_2SO_4 which can be collected by means of electrofilters, concentration of sulphuric anhydride SO_2 decreases with increase of H_2O in emulsion. A significant reduction in the temperature level and uniform distribution of oxidiser and fuel in the combustion chamber leads to a reduction in NOx values.

Conclusion

The effective combustion of WOE with high moisture content, reaching values of 20 %, is made possible by recreating a forced vortex motion of the fuel-air medium. A positive criterion is achieved by an increased degree of mixing and high angular flow velocities (Figure 4).

Figure 4 – Combustion process of WOE with 20 % water content

A prototype of the burner showed the prospects of introducing cyclone-vortex technology in boiler technology, which is confirmed by an increase in their heat output, economic efficiency and a significant reduction of harmful emissions [19].

Experiments have shown that combustion of fuel oil in the form of water-oil emulsion in an innovative swirl burner reduces the emission of harmful substances into the atmosphere. Compared to conventional oil, HFO with 20 % water content reduces SO_2 and NOx by 29 % and 58 %, respectively. Further increasing the water content in WOE leads to failure of flame stability and reduces the efficiency of the burner. When oil-water emulsion is combusted in the innovative swirl burner, the concentration of incomplete combustion products is reduced due to improved formation of the fuel-air mixture.

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ИСПОЛЬЗОВАНИЕ ВОДОМАЗУТНОЙ ЭМУЛЬСИИ В ВИХРЕВЫХ ГОРЕЛОЧНЫХ УСТРОЙСТВАХ

Эффективное сжигание нетрадиционных видов топлива в последние годы вышло на одно из первых мест в исследованиях учёных многих стран в связи с ускоренно истощающимися запасами ископаемого топлива. С развитием компьютерной техники всё больше внимания уделяют моделированию с использованием широкого спектра специализированного программного обеспечения в убыток более точным экспериментальным исследованием в связи с дорогостоящим лабораторным оборудованием и расходными материалами. В данной статье кратко приводится обзор экспериментальных исследований связанный с подготовкой и сжиганием водомазутной эмульсии (ВМЭ) с пояснением процесса микровзрыва капель топлива и зависимостью эффективности сжигания от процентного содержания воды в топливе. Проведён эксперимент по сжиганию ВМЭ с использованием запатентованного инновационного горелочного устройства для широкого спектра жидких и газообразных видов топлива. На основе ранее опубликованной статьи с описанием изготовленного авторами волнового диспергатора была подготовлена и сожжена смесь мазута с концентрациями воды 5 %, 10 %, 15 % и 20 % в ВМЭ и один раз чистый мазут. Результаты анализа данных по вредным выбросам демонстрируют снижение по мере повышения содержания влаги в топливе. Наиболее оптимальное содержание влаги по показателю тепловыделения в водомазутной эмульсии на уровне 20 %.

Ключевые слова: водомазутная эмульсия, диспергатор, микровзрыв, вихревая камера сгорания, вредные выбросы.

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МҰНАЙ-СУ ЭМУЛЬСИЯСЫН ВОРТЕКС ОТТЫҚ ҚҰРЫЛҒЫНДА ПАЙДАЛАНУ

Дәстүрлі емес отынды тиімді жағу соңғы жылдары қазба отын қорының тез таусылуына байланысты көптеген елдер ғалымдарының зерттеулерінде алғашқы орындардың біріне шықты. Компьютерлік технологияның дамуымен қымбат зертханалық жабдықтар мен шығын материалдарының арқасында дәлірек эксперименттік зерттеулер есебінен кең ауқымды арнайы бағдарламалық қамтамасыз етуді қолдану арқылы модельдеуге көбірек көңіл бөлінуде. Бұл мақалада отын тамшыларының микрожарылу процесін және жану тиімділігінің отындағы судың пайызына тәуелділігін түсіндіре отырып, су-мұнай эмульсиясын (СМЭ) дайындау және жағумен байланысты эксперименталды зерттеулерге қысқаша шолу жасалады. Сұйық және газ тәріздес отындардың кең спектрі үшін патенттелген инновациялық оттықты пайдаланып СМЭ жағу эксперименті жүргізілді. Авторлар шығарған толқынды дисперстерді сипаттайтын бұрын жарияланған мақалаға сүйене отырып, СМЭ-де су концентрациясы 5 %, 10 %, 15 % және 20 % болатын мазут қоспасы және бір рет таза мазут дайындалып, жағылды. Зиянды шығарындылар туралы мәліметтерді талдау нәтижелері отын құрамындағы ылғалдылық жоғарылаған сайын төмендегенін көрсетеді. Су-мұнай эмульсиясында жылуды бөлу бойынша ең оңтайлы ылғалдылық 20 % деңгейінде.

Кілтті сөздер: су-мұнай эмульсиясы, дисперсия, микрожарылыс, құйынды жану камерасы, зиянды шығарындылар.

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