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SOME UNIQUE FEATURES OF HEAT LIBERATION IN BOILING OF HYDROCARBON FUELS IN LARGE VOLUME

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Heat liberation coefficients are measured for boiling of hydrocarbon fuels in large volume at pressures up to 0.31 MPa. It is established that oxygen dissolved in the fuels encourages formation of precipitates and affects heat exchange during boiling. The dependence of the heat liberation coefficient upon thermal flux and pressure is presented for bubble boiling of deoxygenated fuels.

At the present time the literature has accumulated a wide amount of material on heat liberation upon boiling of various individual substances, including hydrocarbons, from a large volume. There is significantly less data available on heat exchange during boiling of multicomponent hydrocarbon mixtures, and in particular, data on wide fraction petroleum products is quite limited [1].

The present study will offer results of an investigation of heat liberation during boiling in a large volume of the fuels RT (GOST 10227-86) and T-6 (GOST 12308-80), two substances with markedly differing physicochemical properties. The experiments were performed in an apparatus (Fig. 1) consisting of a cylindrical bath 1, 0.15 m in diameter and 0.22 m high, with three view windows 2 equally spaced around the lateral surface and one window in the bath lid. Liquid boiling occurred on a horizontally oriented tube 3, made of 12Kh18N10T stainless steel, with outer diameter 0.00705 m, inner diameter 0.00605 m, and length 0.143 m, which was heated by an electrical current. The tube surface finish corresponded to that of seamless tubing.

The vapors of the boiling fuel were condensed in a glass condenser 4, installed on the bath lid, or on a water-cooled metal condenser. The glass condenser was used in experiments performed at atmospheric pressure and the metal one, above atmospheric pressure.

To maintain saturation temperature in the boiling volume the condensate was collected by baffle 5 and subfloor 6 and returned to the boiling volume by heated tube 7. Moreover, compensation heaters and a layer of asbestos insulation on the bath side wall were used for the same purpose. In the experiments at elevated pressure the latter was created by vapor

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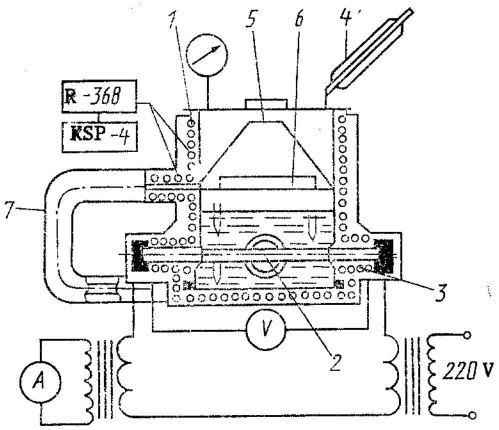

Fig. 1. Diagram of experimental apparatus.

formation and regulated by varying the condensation rate, i.e., the cooling water flow rate. The pressure was determined from dependences of pressure upon saturation temperature available in the literature for RT and T-6 fuels, and varied from 0.1 to 0.31 MPa. The temperature of the inner wall of the boiling tube was measured (two movable thermocouples introduced to the interior by a current buss) together with the temperature of the boiling liquid at two points within the volume. The thermal flux into the liquid was determined from the voltage across and current in the boiling tube. The temperature of the tube outer surface was calculated with consideration of the temperature change through the wall. Each experiment lasted 3 hr.

Preliminary experiments on boiling of distilled water in the large volume showed good coincidence of the results obtained with known data [3].

Figure 2 shows heat liberation coefficients for the fuels RT and T-6 as functions of thermal flux density. It is evident that in logarithmic coordinates the slopes of the straight lines $\alpha = \alpha(q)$ decrease markedly with increase in pressure. It is interesting that while in the region of well developed bubble boiling of individual hydrocarbons the exponent in the dependence $\alpha = Aq^n$ is usually equal to $n \approx 0.7$-$0.8m$ for boiling of RT and T-6 (at P = 0.31 MPa) this exponent is equal to $n = 0.55$ and 0.4 respectively.

Use of calculation expressions proposed for single-component liquids revealed their inapplicability for describing heat liberation during boiling of the fuels. Thus, heat liberation coefficients calculated with Labuntsov's well known criterial equation [4] proved to be at least 1.5 times higher than those determined experimentally for RT and T-6.

A unique feature of petroleum products in general, and fuels in particular, is a reduction in their thermo-oxidation stability as they are heated, which is accompanied, as is well known [5], by precipitation of hydrocarbon compounds on the heat transporting walls of the channels.

One of the fundamental thermochemical mechanisms for precipitate formation is that of oxidation of molecules of unstable components contained in the fuel by dissolved oxygen [6]. The free radicals which thus develop react with each other and fuel molecules with formation of high molecular mass products, of which the precipitates are formed. The density (≈ 800 kg/m^3) and concentration of hydrocarbons in the liquid phase ~4-5 moles/liter) is at least an order of magnitude greater than the density and concentration of vapor phase hydrocarbons. Therefore the hydrocarbon oxidation rate, and thus, intensity of precipitate formation in the liquid phase is significantly greater than in the vapor phase.

In connection with this, the rate of the oxidation reaction increases with increase in temperature of the medium under conditions where the liquid-vapor phase transition is possible, the maximum precipitate formation rate should occur near the point of phase transition from the liquid side. Removal of the oxygen dissolved in the original fuel should, on the whole, encourage a reduction in the quantity of precipitate formed in the liquid phase.

To evaluate the effect of dissolved oxygen on precipitate formation and heat liberation during boiling in a large volume comparison experiments were performed (of the same duration) on the original (with volume oxygen concentration $C_{O_2} = 5\%$) and deoxygenated fuels.

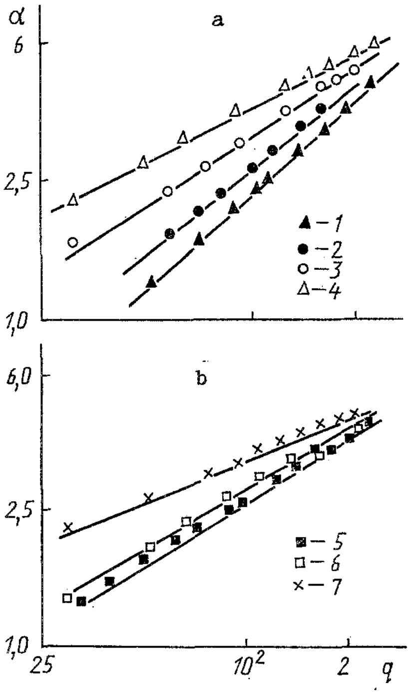

Fig. 2

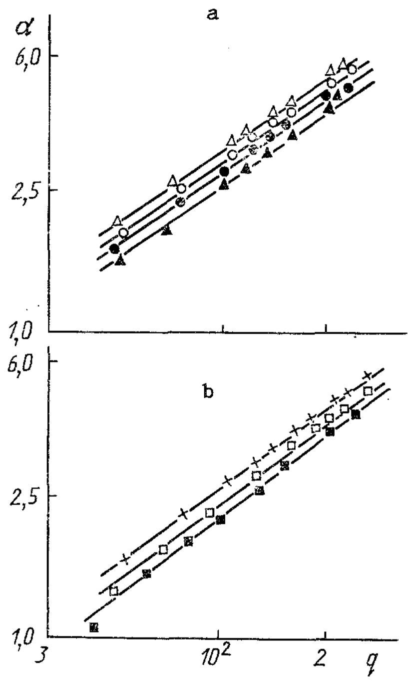

Fig. 3

Fig. 2. Heat liberation coefficient, kW/($m^2 \cdot K$) vs thermal flux density, kW/m^2, for boiling of fuels RT (a) and T-6 (b) in large volume; C_{O_2} = 5 vol. %: 1, 5, P = 0.1 MPa; 2, 0.149: 3, 0.218; 4, 0.31; 6, 0.127; 7) 0.182.

Fig. 3. Heat liberation coefficient, kW/($m^2 \cdot K$) vs thermal flux density, kW/m^2, for boiling of deoxygenated fuels RT (a) and T-6 (b) in large volume; C_{O_2} = 0.3 vol. %: notation as in Fig. 2.

The deoxygenation was carried out by bubbling nitrogen through the fuel held in the bath for 2 hr. The residual oxygen concentration did not then exceed 0.3 vol. %. Further decrease in oxygen concentration for bubbling beyond 2 hr was insignificant. At the completion of the experiments the deoxygenated fuels remained transparent while the original ones became quite dark: the RT took on a yellow color, while the T-6 turned red. The surface of the boiling tube remained practically clean, with the exception of vapor formation centers, about which ring-shaped deposits appeared, with maximum thickness at the inner surface of the ring. Meanwhile the tube used to boil the original fuels became completely coated with a thin layer of hydrocarbon precipitate.

The experiments revealed that for boiling of the fuel RT at pressure not more than 0.149 MPa the difference in heat liberation for the original and deoxygenated fuels proved insignificant (we note that the heat liberation coefficients were determined at the start of the experiment while the boiling tube surface was still clean). With increase in pressure from 0.22 to 0.31 MPa the intensity of heat liberation for boiling of the deoxygenated fuel proved lower than that of the original (Fig. 3). The decrease in the heat liberation coefficient increased with increase in pressure and at $q = 10^5$ W/m^2 comprised 17 and 33% respectively.

For boiling of deoxygenated T-6 the reduction in heat liberation coefficient (at $q = 10^5$ W/m^2) at pressures of 0.1, 0.13, and 0.182 MPa comprised 19, 23, and 30%. We will note that the heat liberation coefficients for the deoxygenated fuels as calculated by Labuntsov's equation [4] proved to be more than double the experimentally determined values. The experimental results on boiling of the deoxygenated fuels can be described by the expression $\alpha = 0.52q^{0.736}p^{0.27}$.

Thus, study of the principles of heat liberation in boiling of hydrocarbon fuels requires consideration not only of the content of dissolved oxygen, but also change in the state of the heat transport surface due to precipitate formation. Beforehand deoxygenation of fuels encourages a reduction in precipitate formation and reduction in heat liberation intensity.

NOTATION

q, thermal flux density, kW/m^2; α, heat liberation coefficient, kW/(m$^2\cdot$K); P, pressure, MPa; C_{O_2}, volume concentration of oxygen dissolved in fuel, %.

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COMPUTATION OF THE RADIATION FLUX EMANATING FROM A HIGHLY DISPERSE LAYER

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Problems of the radiation of a highly disperse layer and of radiation transfer in a disperse layer-enclosing surface system are examined. The influence is analyzed of nonisothermy on the radiation flux density emanating from the layer. A dependence of this quantity on the system parameters is found.

The necessity for the solution of problems associated with radiation energy transfer in highly disperse media (porous bodies, aerodispersed systems) occurs in the description of many technological processes. In a number of cases the disperse system with moving particles that is under consideration is enclosed in a certain volume such that heat transfer by radiation occurs between it and the enclosing surfaces [1]. If the surface temperature is below the particle temperature, a temperature drop can occur in the disperse medium [2]. The problem of a radiator in which energy releases are realized by atomization of hot fluid drops in cosmic space and cooling them by radiation heat extraction and then collection of the cold particles is examined in [3]. All the problems mentioned are associated with a computation of the heat transfer by radiation from a disperse medium with enclosing surfaces or of heat elimination into outer space.

A survey of the different models utilized to compute heat transfer by radiation in disperse systems in both the case of a fixed skeleton of a porous body and for moving particles of condensed phase (in particular, for fluidized media) is presented in [2, 4, 5]. We shall later use the random walk model of particles (photons in this case) in a macroparticle medium that can be their sources or sinks. According to this model, the disperse medium is simulated by a homoeneous system of chaotically distributed fixed opaque spherical particles of radius r. Such a model is applied in [6] to compute the mass transfer in a subliming porous layer for a free-molecule gas flow. Taking account of the known analogy between mass transfer processes for a free-molecule gas flow and radiation transfer [7], this approach was utilized in [5] to compute radiation propagation in a porous layer. The

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