

Behaviour of a heavy fuel oil droplet on a hot surface

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Received 5 May 2005

Available online 10 November 2005

Abstract

When heavy fuel oil sprayed in droplets burns in water heating boilers, there are cases when the zones of incomplete combustion are present. The volatile compounds and tar contained in the droplets burn out there and the carbon starts to accumulate on the pipes of the screen. Combustion of a fuel droplet on a solid surface is less investigated than that of the droplet falling down in hot air. In this work, the burnout of a droplet of a heavy fuel oil has been measured on a hot surface whose temperature varies in the interval from 400 to 700°C. Times of evaporation of volatile compounds and burnout of the resulting carbon residue were measured. Changes of the form of the carbon residue depending on the surface temperature were recorded. Ceramic, quartz and stainless steel surfaces were used. The effect of surface roughness was additionally examined. In the case of a droplet of the heavy fuel oil dropped on a hot surface, heat transfer into the droplet is very sudden. The surface wetting condition is important, as it determines evaporation and boiling. Another difference from a freely falling droplet is oxidation of the pure coke because the oxygen diffusion is possible only from one side of the space. © 2005 Elsevier Ltd. All rights reserved.

Keywords: Droplet; Surface; Burning; Heavy fuel oil; Coke

1. Introduction

In different technologies there are cases when a fuel droplet heats on the surface, evaporates and burns. In this work, the behaviour of such a droplet is investigated starting from the moment when it is dropped onto the hot surface, evaporates and burns until carbon burns out completely.

The following stages of the droplet combustion process can be distinguished: (i) impact of the droplet against the surface and the surface wetting, (ii) heat transfer from the surface into the boiling droplet, the effect of the thermal conduction and other properties of the surface, (iii) the process of volatile evaporation in the droplet and formation of a solid cenosphere, (iv) tar devolatilization and process of coke (carbon residue) oxidation. With the above issues in mind, we will overview the relevant references.

Combustion of a droplet on a hot surface is analogous to that of a droplet falling in hot air, except for the first stage of the contact with the surface and heating. The general situation can be most obviously understood by looking at the combustion characteristics of a heavy fuel oil droplet in the book of Bartok and Serafim [1]. Canonical laws on the droplet aerothermochemistry are pointed out by Chiu [2] and the calculation procedure is given in the FLUENT code [3]. Combustion of a fuel droplet has to be calculated in six process stages: droplet preheating, surface vaporization, volatile boiling, tar devolatilization into volatile compounds, coke surface combustion and estimation of the inert particle residue.

The FLUENT code, in addition to droplet combustion in the hot environment, contains the schematic modelling of combustion of a particle that impacts a hot surface under a certain angle. The first case is when the particle instantaneously evaporates all the volatile contents after it hits the surface. In the last proposal, there is a case when the flow of elastic particles, according to the laws of the flow hitting the wall, spreads out in a layer whose height

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Nomenclature

a	thermal diffusivity (m^2s^{-1})
c_p	specific heat ($\text{J kg}^{-1}\text{K}^{-1}$)
d	diameter
h	height of roughness element
m	mass
s	step between roughness elements
t	time (s)
T	temperature ($^{\circ}\text{C}$)

Greek symbols

ρ	density (kg m^{-3})
ν	kinematic viscosity (m^2s^{-1})

Subscripts

c	coke
v	volatile

is H at the wall. In order to solve more complex tasks of this type we have to design our own models; therefore, we need the experimental data. For example, there are cases when, as the heavy fuel oil is burned in water heating boilers, fuel begins to carbonize on the cold pipes of the boiler screen and it is necessary to know the time when the coke starts to be deposited and how thick the layer of the coke can grow up. Experiments presented in this work provide partial answers to the latter question.

The first detail of the process is the interaction of the droplet with the surface. Performing the research using high-speed video cameras, a great deal of information regarding the droplet deformation during the impact time was accumulated. The surface tension forces of the droplet, inertia forces and wall wetting are decisive. A droplet ball can hit the wall and rebound as an elastic body. This occurs when the surface is hot, the layer of vapour forms under the droplet, and the droplet rebounds accelerated by the expansion of vapour [4]. From the high-speed recording it can be seen how the droplet spreads on the surface. Depending on the wetting, including the surface roughness, the liquid temperature, the Weber number, the droplet can partially return into the form of continuous liquid or split into fine droplets [5,6]. The critical values of We for elastic rebounding are approximately 60.

The next very important moment is the initial heat exchange. The droplet starts to evaporate instantaneously as it touches a hot surface. At smaller We numbers and lower surface temperatures the droplet wets the surface and there is a rapid bubbling boiling. Thermal flows are very large, 10^5 – 10^6 W/m^2 . Droplet evaporation is more rapid near its boundaries and the characteristics of the thin film evaporation are valid. Bubbles adrifted in the thin liquid film are less intensely cooled on their way and in this case evaporation of the liquid speeds up.

There are many papers regarding the combustion of the droplet suspended in the hot air. We will mention the work by Xu et al. [7], where heavy oil residues were burnt and the size of the droplet was up to 1.7 mm, which is close to the size of our droplet. Here, it was discussed which hydrocarbons dissolve and gasify first. Since the heavy fuel oil droplet is in the environment of hot air, its vapour and then the droplet itself ignite. It should be noted that in the environ-

ment of 775°C , ignition delay of the droplet whose diameter is 1.1 mm lasts for 0.7 s, the flame lifetime is 1.3 s, the coke glowing time is 1.1 s, the coke amber time is 1.3 s. Vil-lasenor and Garcia [8] in their work analyzed how the increased asphaltene content in heavy fuel oil changes the droplet ignition and delays coke combustion due to graphite formation. In Li's work [9], combustion of small fuel droplets as they hit the hot surface was measured. The droplets split into smaller droplets that rebound at a larger rate than the primary one.

Properties of heavy fuel oil should be discussed in greater detail since volatile content is characteristic of all kinds of fuels, and after that—the possibilities of tar formation and decomposition. The phenomenon of pyrolysis is significant. There is a period when the droplet boils and an intense decomposition into simpler compounds occurs inside it. We know from many sources that, starting at 300°C , pyrolysis, volatile emission, tar decomposition begin and all these processes continue up to 550°C . In order to research the properties of our heavy fuel oil more closely, analysis of decomposition of this fuel was carried out in the thermogravimeter. The results are presented and compared with the data from [7] in a separate picture in the next chapter, where the properties of the fuel and the overall methodics of this work are described.

Our laboratory is constantly concerned with the issues of combusting the heavy fuel oil in the most ecological way, of controlling the size of fuel droplets and combustion temperature near the recirculation zone of the quarl in order to minimize the production of nitrogen oxides. It was noticed that the droplet that drops on the ceramic bricks in the boiler burns out, and carbonization begins in other cases. In this work, the behaviour of a droplet of a multicomponential heavy fuel oil on a hot surface is studied, when the wall temperature is 350 – 700°C , i.e., when the heavy fuel oil wets the surface; when after the volatile evaporates or burns only tar and coke remain and how long does it take for this residue to burn out. Dependence on the surface conductivity has been measured: ceramic or metal surfaces. It was recorded how the form of the carbon residue changes as the temperature increases. Results are analyzed according to the previously mentioned laws of droplet combustion in space.

2. Methodology

The heavy fuel oil containing 85% of carbon, 10.5% of hydrogen, 2.5% of sulphur and in total 2% of mechanical impurities, ashes and metals, was used for the experiments. The density of the heavy fuel oil was $\rho = 970 \text{ kg m}^{-3}$, the kinematic viscosity $\nu = 118 \times 10^{-6} \text{ (m}^2 \text{ s}^{-1}\text{)}$, the specific heat $c_p = 2.0 \text{ (kJ kg}^{-1} \text{ K}^{-1}\text{)}$.

The temperature interval of the hot surface was chosen from 350 to 700°C for the experiments, as well as three materials of different thermal conductivity whose coefficients of thermal diffusivity are given in Table 1.

Two experimental set-ups were constructed during the experiments, the schemes of which are presented in Fig. 1. The first investigations were carried out when a droplet of heavy fuel oil dropped and burnt on the ceramic crucible of 13 mm diameter, placed on the hot surface. Later the crucible was replaced by a 100 mm long stainless steel or quartz flute with the internal radius of 30 mm. They were placed into a brick of ceramic foam with an electrical heater. The heater was fastened to a stand, enabling to change the flute inclination. The temperature of the heated surface was measured by the chromel–alumel thermocouple, connected to the digital voltmeter.

The first experiments showed that at the temperature of 450°C, a rapid evaporation of volatile compounds begins, and at the temperatures over 700°C, the droplet always bursts into several smaller droplets and a more detailed measurement of the droplets was not possible. In order to learn better the composition of the heavy fuel oil, and additional research was carried out by means of a thermogravimetric analyzer Q-1500D, in the environments of oxidizing air and inert nitrogen. 220 mg of heavy fuel oil was poured into one of the two corundum crucibles. The heating rate was 10°C/min. The thermogravimetric, differential thermogravimetric and differential thermal curves were measured. In Fig. 2, the thermogravimetric curve in the nitrogen environment is presented and compared with the analogous measurement of Xu et al. [7]. It is seen from

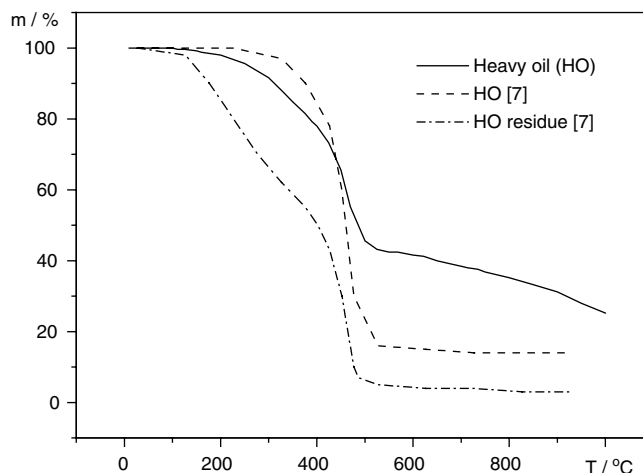


Fig. 2. Comparison of mass reduction curves of heavy fuel oil.

the thermogram that in the range of 300–500°C, dissociation reactions occur intensely and the mass decreases rapidly. In our case the heating rate was higher than that in the mentioned work. From the measurements it can be seen that the solid residue with carbon is more passive and inert than that reported in [7].

During all the experiments the temperature of the heavy fuel oil was maintained the same $76 \pm 1^\circ \text{C}$. The heavy fuel oil droplet was dosaged by a syringe, the needle diameter of which was equal to $0.6 \pm 0.01 \text{ mm}$. The sixth or seventh droplet was directed onto the hot surface because then the sizes of the droplets were the same. The mass of the droplet of the heavy fuel oil was determined by the mass difference method: $m_m = m_1 - m_2$, where m_1 is the mass of a blank paper sheet, and m_2 is the mass of the paper sheet with the heavy fuel oil droplet. One droplet was directed onto a separate paper sheet and weighted by a scale. The measurement uncertainty was 3%. The average mass of the heavy fuel oil droplet was equal to $3.3 \pm 0.1 \text{ mg}$. The diameter of the droplet was calculated from the known mass – 2.3 mm.

Evaporation and combustion of the droplet were recorded by a Sony CCD video camera with the resolution of 768×512 . The image was recorded and later analyzed by a videoplayer. Evaporation of volatile compounds of the droplet was rapid, therefore, this time was measured in slow-motion, i.e., at 25 frames per second. Meanwhile, the burnout of carbon residue lasted for tens of seconds and this time was measured by a timer.

The analysis of photos of droplet evaporation and combustion revealed that volatile compounds boil in bubbles, suddenly evaporate and the metaplastic residue remains, a frame containing tar and carbon, frequently referred to as a cenosphere. After that, the second stage begins, when tar decomposes into heavier gases and a small portion of coal remains on the surface as a spatial structure. From the photos and the glistening of the surface it is seen when the tar decomposition and combustion ends and the coke oxidation begins. From the photos it is seen how the differ-

Table 1
Thermal diffusivity, a , for used hot surfaces materials

	Aluminium oxide	Quartz	Stainless steel
$a \text{ (m}^2 \text{ s}^{-1}\text{)}$	2.4×10^{-6}	3.3×10^{-6}	12×10^{-6}

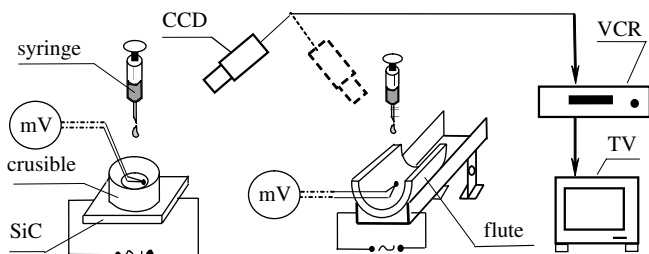


Fig. 1. Experimental layout.

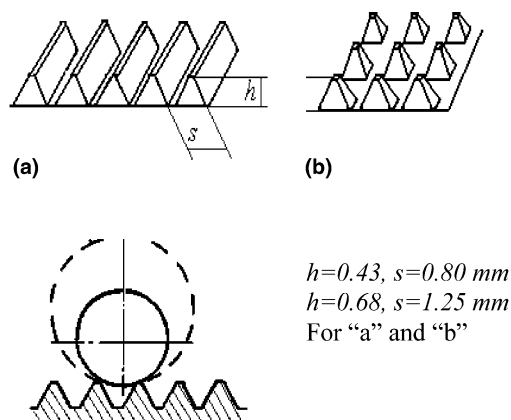


Fig. 3. The shape of roughness elements on the steel surface: (a) cross-incisions and (b) pyramid-shaped elements.

ent shapes of the cenosphere develops as the surface temperature changes—from a hemisphere to a flat surface.

A quartz chip of 532.2 mg was used to determine the mass variations of the evaporated droplet. This chip together with the unburnt mass was suddenly cooled on the cold wet surface and was measured at two time moments: (1) at 2.5–3 s after the droplet had hit the surface, when the carbon and tar structures emerge, (2) at approximately 6.5–7 s after the carbon residue had formed. The mass difference of the quartz chip is equal to the droplet residue mass. For the first moment, the mass was equal to 0.25 mg (with uncertainty of 14%), and for the second moment—0.05 mg (uncertainty 60%).

The major part of the experiments were recorded and the process was analyzed from the photos. The coke oxidation time was long and it was easy to determine its duration. The coke oxidation was considered to be complete when the hot surface became evenly clean everywhere.

For many years heat transfer on the rough surfaces has been investigated at the institute [10], therefore, this measurement was performed in these experiments as well. Rough elements of two kinds of the shape and the height were created in the stainless flute: transverse incisions and pyramids, see Fig. 3. In this figure, dimensions of rough structures are presented, where h is the height of the roughness elements, and s is a distance between two adjacent elements. In total, there were four different types of surface roughness. The droplet of a heavy fuel oil was always larger than the roughness elements.

As it has been mentioned while discussing Fig. 1, the hot flute inclination could be changed and thus it could be measured how fast the droplet rolling on the surface burns out. In all measurements, the droplet was dropped from the height of 70 mm.

3. Results

At low surface temperatures of up to 550 °C, the droplet of the heavy fuel oil is deformed after it hits the surface, but does not splash and remains continuous. Liquid layers that

touch the surface heat up in hundredths of seconds and evaporate intensely. Materials possessing the lowest boiling temperature separate suddenly and form a vapour cushion that separates the droplet from the surface, while the droplet reacquires its initial spherical shape under the influence of the surface tension forces. All this process lasts for less than 40 ms. After the first contact, when the surface temperature drops by more than ten degrees, the second touch begins, the droplet spreads out on the surface because the droplet wets the surface.

Due to intense heat transfer the volatile compounds evaporate and form vapour bubbles near the surface, and then in the droplet volume as well. During 0.8 s after the impact of the droplet onto the surface, the vapour concentration increases significantly and the droplet volume doubles. The intensive surface evaporation of the volatile compounds without the bubble boiling begins at the droplet boundaries where the liquid layer is very thin. The further behaviour of the droplet depends on the temperature of the heated surface and its thermal conductivity.

Ceramic, quartz and steel surfaces were used for the investigations. The experiments have revealed that the droplet behaves the same on all of them, if the real surface temperature under the droplet is taken into account.

On the quartz and ceramic surfaces, at the temperatures lower than 550 °C, when the volume of the droplet doubles, the liquid mass spreads out in the area of approximately 2–2.5 droplet diameter. Its lower layer overheats and the thermal decomposition begins there—unstable bonds between aromatic compounds break. Gases of lower molecular weight create the first vapour bubbles that start merging and bubble boiling regime develops, as seen in Fig. 4. Pictures were selected omitting different time periods. When light fractions evaporate, compounds of relatively large molecular weight remain, from which the carbon residue, also known as a cenosphere, forms. The tar in these cenospheres decompose into heavier gases, oxidize and the volume gradually decreases. Eventually, the coke remains. At this temperature on the non-conducting surfaces, such as ceramics and quartz, shallow porous shells are formed, see “a” case in Fig. 5. On the steel surface, heavy fuel oil mass spreads out in a larger area, evaporation occurs more intensively, therefore, tar and carbon residue is less porous and flat.

From the investigations of the suspended droplet of the heavy fuel oil, the resulting cenosphere consists of the compounds containing more than 85% of carbon, usually tar and coke. Its combustion occurs through the unstable intermediate products, which remain absorbed for a shorter or longer period of time in the surface shell and porous surface and form a certain layer, through which the oxidation occurs. Decomposed intermediate materials react more rapidly with the oxygen and thus the carbon combustion reaction is inhibited. However, hydrocarbons that burn on the surface provide an additional amount of heat and stimulate the processes of cenosphere gasification and pyrolysis. Besides, depending on the temperature, the

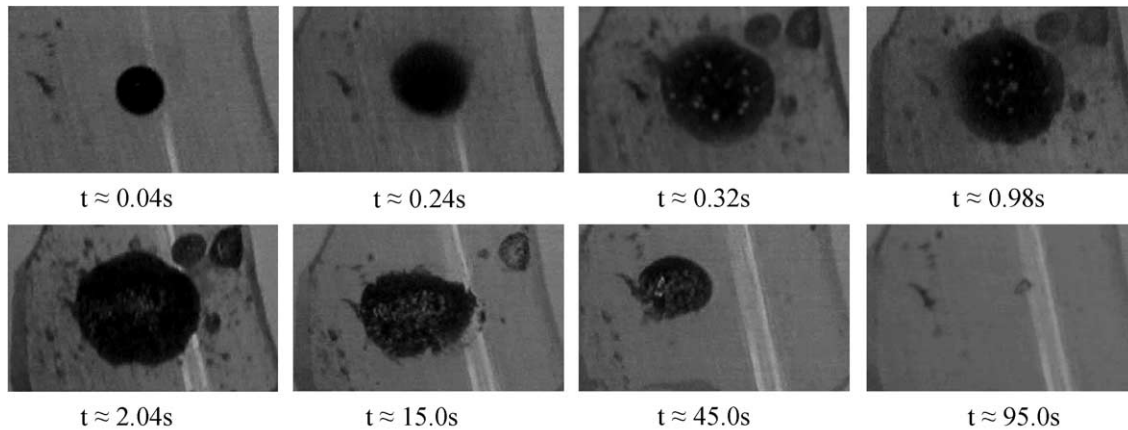


Fig. 4. The heavy oil droplet evaporation and combustion stages.

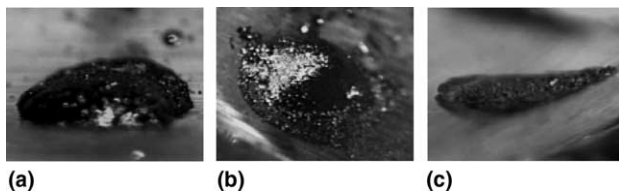


Fig. 5. The shape of the metaplast under the different quartz wall temperatures: (a) $T_w \sim 550^\circ\text{C}$, (b) $T_w \sim 600^\circ\text{C}$ and (c) $T_w \sim 650^\circ\text{C}$.

combustion of intermediate volatile materials, formed from tar, and tar combustion can proceed simultaneously or one after another [11]. As it will be shown below, due to this reason the mass of the remaining carbon residue on the surface is very small.

Having reached the temperature of 600°C , the behaviour of the droplet of the heavy fuel oil on the hot surface changes somewhat. There is no essential difference between combustion of the droplet of the heavy fuel oil on the ceramics or on the quartz: after hitting the surface the droplet remains suspended over the vapour cushion for approximately 1 s, then it blows up and spreads out on the surface in the area of approximately two diameters. Since the temperature is higher, the tension of the liquid surface tend to pull the liquid mass back to the centre where the hollow shell is being formed. Meanwhile, the thin edges cook closely onto the surface. A certain hat-shaped structure forms, case “b” in Fig. 5. It is the edges that burn out longest by the slow oxidation reactions. This is determined by a relatively small coke porosity hindering the oxygen diffusion which occurs from one side only. At the temperature of 650°C , volatile particles evaporate so rapidly that they destroy the shell, which is being formed in the centre, and ignite themselves. After the flame extinction, a thin layer of carbon residue remains around the hollow centre, case “c” in Fig. 5.

At higher surface temperatures, especially on the steel surface, another phenomenon was observed. The droplet which drops on the steel surface whose temperature is $600\text{--}630^\circ\text{C}$, as in the case of quartz and ceramics, remains

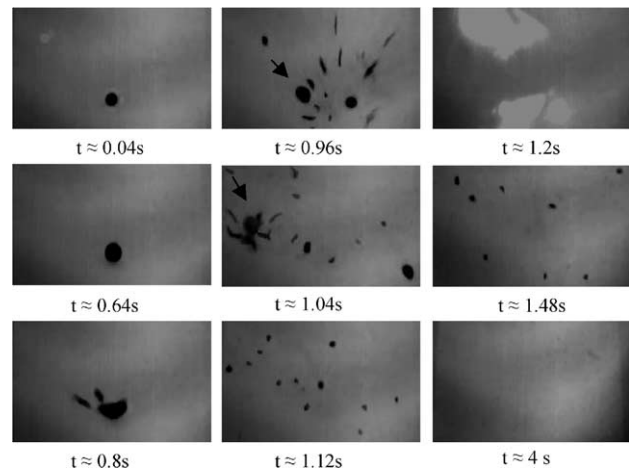


Fig. 6. Evaporation, explosion, ignition and coke burnout stages of the heavy fuel oil droplet onto the smooth stainless steel at $T_w \approx 610^\circ\text{C}$.

on the vapour cushion for the first second. However, after that it does not spread out on the surface but explodes into several smaller particles, Fig. 6. In this picture, the processes progress rapidly and in order to understand this one particle is marked by an arrow. Starting from the frame with the arrow, the flame can be observed that is especially bright in the last frame. The emitted volatile compounds ignite rapidly near the central part of the droplet, when the surface temperature is 650°C . In the case of the steel surface, this happens at the temperature of 600°C . This burst of flame speeds up the combustion of tar and the carbon cenosphere, however, the later burnout of the carbon residue is slow.

Since the temperature is high and at this moment not all the volatile materials have evaporated, smaller droplets hitting the surface do not adhere to the surface. Besides, the vapour works as the reactive elevating force, which throws or pushes small particles towards the front. This kind of “fission” lasts until no more volatile materials remain and the remaining carbon residue adheres to the surface and burns out by slow oxidation. On the ceramics, it occurs when the temperature reaches 700°C .

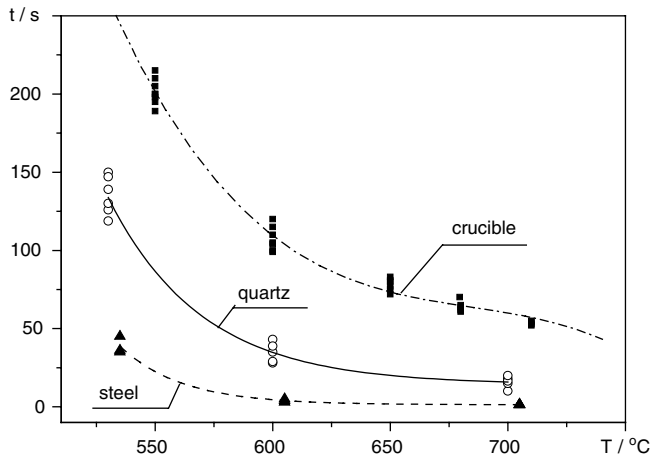


Fig. 7. Comparison of the heavy fuel oil droplet combustion time on the surface with different conduction: aluminium oxide, quartz and steel.

Total combustion time of the droplet was determined from its contact with the surface until the complete coke burnout, when the surface becomes completely clean. These measurements are carried out at different temperatures on all mentioned surfaces. The results are presented in Fig. 7. As it can be seen, the higher is the surface temperature, the quicker the droplet burns out. Combustion time varies depending also on the surface thermal conductivity. In the case of conductive surface, like steel, its temperature drops insignificantly under the droplet, and in the case of quartz, it can drop to 50–70 °C. Taking into account this temperature drop by calculations, the process of the droplet evaporation and combustion is similar, differing slightly because of temporal delay of the wetting, the start of ignition, etc.

The total burning time of a droplet of 1 mm diameter in the crucible is presented in Fig. 8. We succeeded in producing a droplet of approximately this size by applying the impact droplet splatter out of the syringe by means of a special spring. As it can be seen, such a droplet burns out five times faster.

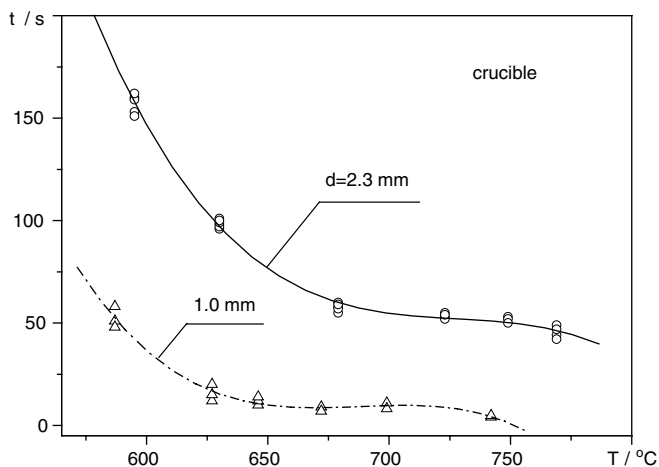


Fig. 8. Combustion time of the heavy fuel oil droplet of two different diameters on the aluminium oxide surface.

The effect of the droplet diameter in the first stage of volatile evaporation can be expressed as the relative change of ratio between the droplet mass and the area of contact with the hot surface. Solution of heat transfer and vaporization balance reveals that as the droplet diameter increases twice, the evaporation period increases twice as well. In measurements this time was not recorded, because the volatile evaporation is very rapid.

The effect of the droplet size manifests itself most obviously in the coke burnout phase. Here, the oxygen diffusion is decisive and the solutions of diffusion apply for determining the duration of combustion for the given geometrical configuration. Since the oxygen diffusion is possible only from one side of the space, the coke burnout time is larger than that of the droplet suspended in the space of hot air. In both cases the outside factors, like the temperature field and coke porosity, play a significant role.

Our measurements can be compared to the combustion times of the freely falling droplet of the heavy fuel oil [7], the diameter of which varied in the range from 0.6 up to 1.7 mm. At the temperature of 1058 K, a larger droplet (1.1 mm) burnt in 6 s. In our case, a heavier heavy fuel oil was used and the combustion time of a 2.3 mm droplet was about 4 s on the steel surface at the temperature of 600 °C.

When the droplet evaporates rapidly and then decomposes and burns, its mass changes. The weight of the residual droplet at the interim moments was measured. Therefore, a quartz chip with the remaining unburnt mass was suddenly chilled on the cold surface and measured in two time moments: (1) at approximately 2.5–3 s after the droplet hits the surface, when the carbon and tar structures are formed; (2) at 6.5–7 s after the carbon residue is formed. These results are presented in Fig. 9, where three phases are distinguished: evaporation, the tar pyrolysis with ignition and the coke oxidation. It is interesting to note that in the first and in the second stages, the loss of mass is rapid,

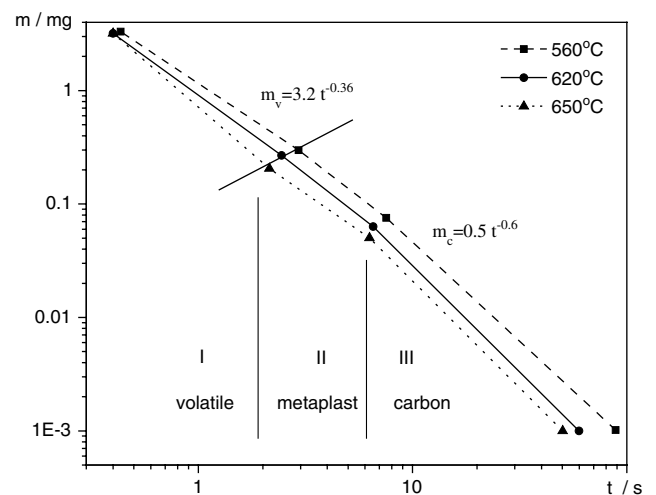


Fig. 9. Mass reduction curves of the droplet at different temperatures: (I) evaporation of the volatiles, (II) decomposition of metaplast, (III) burnout of coke. Surface—quartz.

especially in the first stage of the volatile evaporation. The dependence on the temperature in these coordinates is insignificant. The coke burnout is longest, because the surface temperature used in the experiments is relatively low, the combustion reactions produce less heat in the case of coke, and the oxygen diffusion takes place from one side only. Diffusive oxidation of a thin layer of carbon was calculated with the FLUENT code and the combustion time was found which is close to the measured one.

Since roughness intensifies the heat transfer, roughness elements were formed on the steel surface, whose height and stride were smaller than the droplet of heavy fuel oil. The effect of the surface shape manifest itself through the wetting area of the surface, when the metaplast film is formed after the volatile particles have evaporated and it spreads out according to the geometry of the roughness elements. The transverse recesses are desirable for the range of 450–500°C, and the pyramids—in the range of 500–550°C. The surface wetting is most efficient in this case, the surface roughness facilitates the spread out of the heavy fuel oil by its capillary attraction and, in turn, the droplet combustion. Combustion acceleration is observed when, after the droplet evaporates and the major part of tar decomposes, the coke remains in several separate islands and the oxygen diffusion has a wider space. Combustion time decreases by a factor of 1.3. Starting from 600°C, more rapid evaporation forces the droplet to move quicker and to decompose. Relatively large amounts of it accumulate in the roughness holes and the combustion time is 2–3 times longer.

Comparing the obtained results with the duration of combustion of a heavy fuel oil droplet on a flat surface, it was noticed that more rapid combustion on the rough surface is possible only at the temperatures lower than 600°C and only on the surfaces with higher roughness elements, in which case the droplet burns about 25% faster. At the temperatures higher than 700°C, the droplet dropped on the surface bursts into smaller droplets, whose combustion time does not depend on the surface roughness.

Quartz, smooth and rough steel surfaces were used to investigate the effect of the droplet impact angle upon the surface to duration of combustion. Summarizing the observed results, it was noticed that at the temperatures lower than 550°C, the droplet of the heavy fuel oil wets the surface and leaves a continuous trail as it rolls on a rough or quartz surface. Since the droplet attains higher velocity as the contact angle is reduced, the mass of the heavy fuel oil stuck to the surface spreads out in a larger area, therefore, the combustion time reduces by several times. However, at higher temperatures a vapour cushion forms between the surface and the droplet, on which the droplet rolls. Therefore, as the contact angle decreases, it takes longer for the droplet to heat, evaporate and burn. It should be noted that a vapour cushion forms starting at the surface temperatures of 450°C on the smooth steel surface, therefore, as the droplet rolling velocity increases, its combustion time increases in the whole investigated range of temperatures.

4. Conclusion

Combustion time of the heavy fuel oil droplets with the diameters of 2.3 and 1 mm dropped on the hot surface with the temperature of 400–700°C was measured in this work. A heavier fraction of the fuel oil was chosen, with the density of about 1000 kg/m³. This fuel contains more asphaltenes, burns slower and, for example, cokes more on the surfaces of boiler screens. In the experiments, various hot surfaces were used made from materials of different thermal conductivities: quartz, aluminium oxide and stainless steel. Measurements were made on both smooth and rough surfaces as well.

The process of the droplet combustion and its characteristics is investigated in details in the case of a droplet suspended in hot air. In our experiment, heat is supplied very suddenly to the droplet which is dropped on the hot surface, especially at the initial moment. Other differences is the condition of the droplet adherence to the surface and possibility of diffusion of volatile compounds and oxygen from one side only. Results obtained from the measurements are interesting and they can be highlighted with the following conclusions:

1. At lower surface temperatures of 400–600°C, the droplet cools the surface by 30–70°C at the first touch and after some vibrations the elastic rebound adheres to the surface thus occupying the area of approximately twice its diameters and boils in bubbles. At the temperatures of over 650°C for a metal surface and at 700°C for a quartz surface, film Leidenfrost boiling takes place, when the droplet bursts into several smaller droplets and burns after it has rolled on the vapour cushion. In the latter case, the droplet of 2.3 mm burns out completely in 4–5 s, while in the first case of adheres the droplet evaporation and coke combustion last for many times longer.
2. In the case of surfaces wetting, the volatile compounds evaporate differently depending on the surface temperatures. At the temperature of 400°C the liquefied fuel oil spreads out more and the volatile compounds evaporate by the surface evaporation at the thin edges, whilst the bubble boiling occurs in the central part of the mass, where the carbon and tar structures remain after the volatile compounds have evaporated. At 550°C, intense sudden boiling inhibits spreading of the liquid on the surface and the tar structure assumes the shape of a hemisphere. In both cases, the approximately estimated volatile evaporation rate reaches -1.2×10^{-6} kg/s.
3. The metaplast structure remaining after evaporation of the light gases contains large amount of tar. Oxidation takes place and, when the temperature of the metaplast structure rises, tar decomposes into gases of larger molecular weight and carbon. It should be noted that a large amount of carbon is carried away in this period. The approximate rate of mass loss in this case is -4×10^{-8} kg/s.

4. Oxidation of the left pure coke, constituting only 2% of the initial droplet mass, has the longest duration in time. The process is limited by the molecular diffusion of oxygen to the surface. Note that this spatial structure of carbon burns out faster than the flat layer. The calculation of the carbon flat layer combustion time using the FLUENT code shows the agreement with the experiment and confirms the diffusion phenomenon.
5. Different thermal conductivities of the hot surfaces influence the results as a variation of the boundary condition: the droplet on a quartz surface cools down the elements under it whose size is approximately four times the droplet mass and it can be assumed that the process proceeds from a lower level of the temperature, which is not the case on a metal surface. Taking into account this difference, the processes of the droplet evaporation and combustion are similar in both cases.
6. The surface roughness is favorable when it stimulates the surface wetting, the contact area increases and the burnout time reduces by up to 1.3 times. The surface roughness is not favorable when it stops the dilatation of the droplet or when the small particles of the decomposed droplet fall in cavities. Roughness has no effect to combustion process at temperatures higher than 700 °C, when the droplet explodes.
7. The droplet which rolls through the hot surface burns out faster only if it wets the surface while rolling and leaves the trace. On the metal surface at the temperature

higher than 400 °C, the droplet rolls on the vapour cushion and its combustion time is significantly longer.

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