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Water temperature influence on the spherical body's falling velocity

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ABSTRACT

An article represents the results of the experimental investigation of the falling velocity dependence on the spherical body's metal type, size and Leidenfrost effect for the different temperatures of the body and water. It was stated that the growth of the body's temperature increased the falling velocity due to the change of the water parameters (density, phase, etc.) nearby the surface of the body. Maximal augmentation of the velocity (37–38%) was noticed for the sphere which temperature was equal to 650 °C and water temperature was close to the saturation temperature (99 °C). Falling velocity of the sphere made from the steel was almost the same like of that made from the copper; falling velocity of the aluminum sphere was much less due to the less mass of it. Bigger bodies had greater velocity because of the bigger mass and relatively less resistance.

Augmentation of the falling velocity did not correspond directly on the body's temperature growth. There existed an appropriate interval of the body's surface temperature for which the falling velocity was the highest. Difference between the falling velocity of the hot and cold bodies increased gradually with the rise of the falling time and reached 25% for the stainless steel sphere which temperature was 410 °C and water temperature was 14 °C.

1. Introduction

Reduction of the resistance of the body moving in the liquid is one of the main problems for the hydrodynamics. Lower resistance means higher body's velocity and less energy consumption. Recently are proposed a lot of new methods allowing reducing body's resistance: using polymeric additives or coating [1], injection of the air bubbles into the liquid [2,3], vibration of the body [4], hydrophobic coating [5], elastic coating [6], cavitation [7,8] and etc. Usage of those methods usually acts on the physical properties of the body's surface (roughness, elasticity and etc.) or on the reduction of the liquid density nearby the body's surface. Application of the boiling crises (Leidenfrost effect) can be treated as one of the newest technologies allowing reduction of the body's resistance [9–11]. That effect usually can be noticed on the body's surface which temperature is higher than the saturation temperature of the liquid (water). Steam film (layer), generated on the hot body's surface, separates the body from the main volume of the liquid, therefore a resistance sufficiently reduces and body's velocity increases. Body's surface temperature which influences on formation of the Leidenfrost effect, depends on the body's shape, size, velocity, heat conductivity, heat capacity, density, on the body's dimension, and on the heat transfer rate between the body's surface and the liquid [12,13].

An article represents the results of the experimental investigation of the influence of the temperature, Leidenfrost effect, size and body's metal type on the velocity of the spherical body falling in the water under the different temperatures of the body and water.

2. Methodology

During the experiments were used spherical samples of the same roughness made from the different metals: stainless steel (diameter 0.02 m), bearing steel (diameters $d = 0.01$; 0.022; 0.028 and 0.035 m), copper (diameter $d = 0.02$ m) and aluminum (diameter $d = 0.02$ m) (Fig. 1). Physical properties of the samples (spherical bodies) are presented in the Table 1.

Samples under the influence of the gravity (buoyancy) were falling inside the vertical channel filled by the water. Channel's height was $h = 1.5$ m; square cross section was $0.14 \times 0.14\ m^2$. In order to observe visually the fall of the body the walls of the channel were made from the transparent material. Temperature of the cold body was $T_1^c = 14$ °C, initial temperature of the hot body was $T_1^h = 650$ °C; initial temperature of the water was $T_4 = 14$, 30, 60, 80 and 99 °C. Temperature of the samples and of the water was measured by E type thermocouples (measuring range was $-50 \div 750$ °C).

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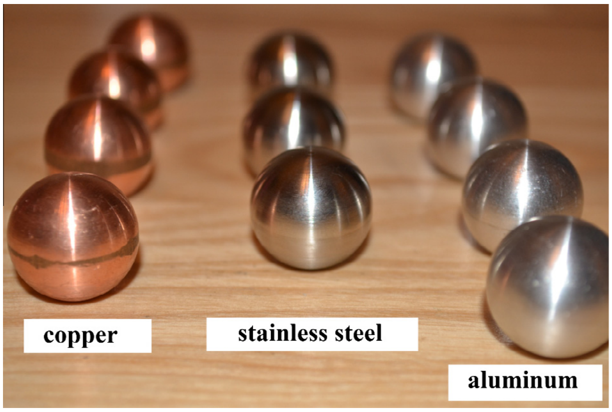

Fig. 1. Experimental samples.

Falling velocity of the cold and hot body was measured and recorded using special measuring technic (Fig. 2), which consisted of two photo gates, allowing metering of the falling velocity. Another part of the measuring technic was the system of the sensors *Nova Link*, which was used for the parallel data collecting and transporting to the computer. In the computer was installed *Multi Lab* data processing system. The first gate was installed at 0.05 m below the water level and the second gate – at 1.43 m below the water level. The experimental sample, falling in the channel, crossed an infrared beam of the gates and an electrical impulse was generated. Mean velocity was calculated by dividing distance between two gates by the time difference of the crossing each gate.

In order to reduce an error of the measurements all experiments were repeated 10 times for each combination of the temperature. Measurement results of the mean velocity w_{mean} are presented in the Table 2. Deviation of the experimental results varied from 2% to 7%.

3. Results and discussion

3.1. Influence of the body's temperature

The results of the experimental investigation of the spherical body, made from the stainless steel, falling down in the cold water are presented in the Fig. 3. Initial temperature of the water was 14 °C, body's temperature was 300 °C. Under such conditions steam film on the body's surface was formed very quickly, however this film disappeared very soon also. Duration of the steam generation was 0.15 s only. Main reason of that was low water temperature (much lower than the saturation temperature) and high heat capacity of the water.

Fig. 4 demonstrates the spherical body falling down in the hot water (water temperature was 99 °C). In this case the steam film existed about 3 min. The turn of the film boiling regime to the bubble boiling regime was accompanied by steam explosion. Differently from the sphere fall into the cold water there was no bubbles' trace following the falling body.

Fig. 5 presents the influence of the body's temperature on the body's falling velocity. Temperature of the water was constant and equal to 14 °C; temperature of the spherical body, made from the stainless steel, varied from 14 to 700 °C. It was noticed that the maximal velocity corresponded to the range of the temperature from 300 to 400 °C. Main reason for that was the influence of the steam generation process. Reduction of the water–steam mixture density nearby the hot body's surface increased the falling velocity by 25% approximately in comparison with the falling velocity of the cold body. Although further augmentation of the body's temperature acted on the more intensive steam generation; intensification of the steam film breaking away process slowed down the motion of the body because of the effect of the surface tension forces (it is valid for the small bodies only). In general it can be concluded that the augmentation of the falling velocity did not correspond to the body's temperature growth. There exists an appropriate interval of the body's surface temperature for which the falling velocity can be the highest. As it was mentioned before the maximal velocity of the body's falling into the cold (14 °C) water can be reached for the body's surface temperature equal to 300–400 °C.

Table 1
Physical properties of the samples.

Parameter	d, m	c_p, J/(kg K)	ρ, kg/m^3	ρ^{650}, kg/m^3	λ, W/(m K)
Bearing steel	0.01; 0.022; 0.028; 0.035	470	7830	7670	48
Stainless steel	0.02	500	7800	7625	15
Copper	0.02	386	8960	8680	401
Aluminum	0.02	840	2700	2580	237

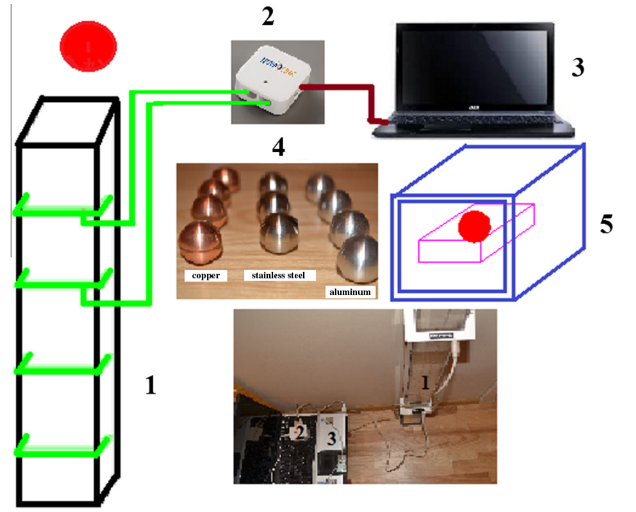

Fig. 2. Velocity measuring system: 1 – water channel; 2 – data collecting system; 3 – computer; 4 – spherical samples; 5 – heating device.

3.2. Influence of the falling time

Fig. 6 represents the influence of the falling time on the spherical body's velocity. Continuous lines show the velocity obtained by the numerical modeling [14] for the cold body (14 °C) falling in the water at the temperature equal to 14 °C. Rectangular dots matter the experimental data for the cold body falling in the cold water; round dots express the experimental data for the hot body (initial temperature was equal to 410 °C) falling in the cold water.

For the numerical modeling a three-dimensional model of the spherical body was established using SOLIDWORKS program. Radius of the spherical body was 0.02 m. Then the model of the spherical body was imported into ANSYS CFX program code. There was selected tetrahedron type mesh for the application of the finite element method. Number of elements was changed from 1 to 4 million and for the modeling of the spherical body was chosen 1.4 million elements. Body was placed in the channel, outside walls of which were modeled as the free surfaces. Water velocity at the inlet to the channel was changed from 0.01 to 2 m/s; static pressure at the outlet from the channel is constant and equal to 0 Pa. Temperature of the water was 14 °C; pressure is equal to 101 325 Pa. Temperature of the bodies was kept at the 14 °C.